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This student instruction manual was written in conformance with selected criteria for programed instruction books as developed previously for various military training courses. The manual was developed as a part of "A Study of the Effectiveness of a Military-Type Computer-Based Instructional System When Used in Civilian High School Courses in Electronics and Automechanics" (VT 006 916). The material concentrates upon knowledge required for logical and systematic gathering of symptoms, analysis of these, and a logical step-by-step methodology of isolation to a section, a component, renewal and replacement or direct repair of the component and then an operational check to determine that the automobile will perform satisfactorily. Subject matter areas and sub-topics include (1) ignition system, functional description and components of the ignition system, (2) fuel system, purpose of the fuel system, fuel components, and operational combination requirements, (3) Engine analysis, basic starting tests and detailed tests for hard starting, and (4) tune-up procedures, types of test equipment, engine tune-up, and road testing. The activities included are those which can benefit the most from a systematic approach applicable generally to any problem which might arise. (HC)

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AUTO MECHANICS

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METHODOLOGY

TECHNICAL INSTRUCTION MANUAL

PREPARED FOR

DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
U.S. OFFICE OF EDUCATION

GRANT NO. OEG 1—6—000242—0618

BY

VT001950

SYSTEMS OPERATIONS SUPPORT, INC.
580 SHOEMAKER ROAD
KING OF PRUSSIA, PA. 19406

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KING OF PRUSSIA, PA., 19406

14 September 1966

Preface

This "Auto Mechanics Methodology" book was written in conformance with some of the selected criteria for programmed instruction books. It concentrates on an area of knowledge required for the competent auto mechanic — namely, logical and systematic gathering of symptoms, analysis of these, and a logical step-by-step methodology of isolation to a section, a component, removal and replacement or direct repair of the component, and then an operational check to determine that the automobile will perform satisfactorily. All superfluous information or checks which are specific to a given make of car, carburetor, etc. are left to the service manuals produced by their respective manufacturers.

Subject matter areas in the text include the ignition system, fuel system, engine analysis and tune-up procedures; e.g., those activities which can benefit the most from a systematic approach applicable generally to any problem which might arise. Various skill areas such as body work, wheel alignment, lubrication procedures, etc. are left to the more conventional repetitive training techniques.

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Gilbert B. Rozran, Ph.D., President
Systems Operations Support, Inc.

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I. INTRODUCTION:

Most of you are already familiar with the basic operation of the four-cycle gasoline burning automobile engine, but we would like to take the time and space here to quickly review its operation. Not because we think you've forgotten, but to help set a stage which will allow us to introduce and discuss, in detail, the basic principles of automotive fuel and ignition systems. We hope also to be able to show the dependence and interaction of these systems with each other and to provide you with an overall and integrated view of this operation.

You remember that as the piston moves up and down in the cylinder, it causes a pressure or suction on top of it, depending on which way it is moving. As the piston moves down, the resulting suction above it draws air and fuel through the carburetor, through the intake valve and into the combustion chamber. As the piston moves to the bottom of the stroke, the intake valve closes and seals the combustion chamber air tight.

Next the piston moves up in the cylinder, traps the explosive mixture above it and compresses it tightly. When the piston approaches the top of its stroke, which is called top dead center (TDC) a spark is passed through the thoroughly dry tightly packed explosive mixture. The fuel particles ignite and the flame passes quickly from one end of the combustion chamber to the other. The result in heat from this explosive burning of the fuel/air mixture causes the trapped gas to expand rapidly, developing almost two tons of pressure on top of the piston. This pushes the piston down and turns the crankshaft. Naturally, both the intake and exhaust valves must close air tight or some of the pressure will escape and the engine will lose power.

As the piston approaches the bottom of the power stroke, the exhaust valve opens, and because of combustion pressure within the cylinder, some of the burned gasses pass out of the engine. The piston returns to the top of its stroke, forcing the remaining burned gasses out through the exhaust system.

As the piston reaches the top of the exhaust stroke, the same sequence of events occur again: intake stroke (piston goes down—intake valve opens—air/fuel mixture drawn into the combustion area); compression stroke (piston goes up—both valves close—mixture trapped and compressed); ignition (spark passes through the compressed air fuel mixture which burns rapidly); power stroke (piston driven down— both valves closed—this is the one stroke in which the power is developed); and the exhaust stroke (piston goes up—exhaust valve opens—burned gas driven from the combustion chamber). Note that ignition is not considered one of the cycles, but takes place near the end of the compression stroke and initiates the power stroke.

This sequence of events is called the four-stroke cycle because of the four strokes which make up each cycle: intake, compression, power and exhaust. The cycle is repeated regularly. Two complete revolutions of the crank shaft are necessary for each power stroke to occur or for each cycle to be completed once. Each cylinder passes through this four-stage cycle, but the cycles are staggered so that each cylinder is fired in an order which develops a relatively smooth flow of power.

Producing a power stroke is the essential product of a four-cycle engine. In our brief description of the four strokes involved, we assumed that the fuel/air mixture is present as well as the spark to ignite it. But we were only describing the most basic principle. Means of supplying the fuel/air mixture and spark must exist. They are also necessary and essential parts of a four-cycle internal combustion engine.

However, the main function of all essential parts of the engine is to develop the most efficient power stroke possible. The power stroke is the only means of developing power. Everything attached to the engine either uses the power developed here or performs some function in enabling the development of the power stroke.

Again, how many crankshaft revolutions are completed for a single ignition? The piston moves completely up and down the cylinder for each crankshaft revolution. This completes two strokes. It takes four to produce one power stroke (where ignition occurs) or two crankshaft revolutions.

For convenience, let's discuss the ignition system first. We'll presume, for the time being, that a combustible mixture of gasoline and air is able to be prepared and packed into the combustion chamber of each cylinder and is also able, when it is ignited, to produce the power stroke of the four-stroke cycle.

II. THE IGNITION SYSTEM:

A. Functional Description

As the fuel/air mixture is being compressed in the combustion chamber of the cylinder, it is only necessary to ignite it in order to enable the power stroke. The problem is how to ignite the mixture. The method used in a four-cycle gasoline burning engine is to cause a spark at the end of the aptly named spark plug. This is the primary function of the ignition system.

The spark plug is so constructed that when a high voltage charge of electricity is applied to the spark plug terminal, it will jump from the center electrode to the ground electrode. This spark causes the fuel/air mixture to begin to burn (See Fig. 1). We'll discuss the spark plug itself later. Right now, let's concern ourselves with getting a spark.

How much electricity is needed to jump the spark plug gap? All the electricity that is available in an automobile is usually 6 or 12 volts. Six or 12 volts from an automobile battery doesn't give a person a shock, not even a tingle, let alone cause a spark to jump across an air gap. It appears that some voltage greater than 6 or 12 volts is going to be necessary to ignite the fuel/air mixture. In fact, it takes approximately 20,000 volts.

Now where is the 20,000 volts going to come from? It is known that in an electrical transformer, voltages can be increased with a corresponding decrease of current (amperes). Automotive engineers have developed a form of transformer — the ignition coil. With this device, the 6 or 12 volts in the automobile electrical system can be raised to 20,000 volts.

How is this accomplished? Having a knowledge of what happens when current flows through a conductor will help in understanding how an ignition coil provides 20,000 volts from a 6 or 12 volt source. Two principles of electromagnetism are involved. First, when a current flows through a conductor, a magnetic field will surround it. Second, when a conductor is moved through a magnetic field, current will be induced in it. If you are not familiar with these

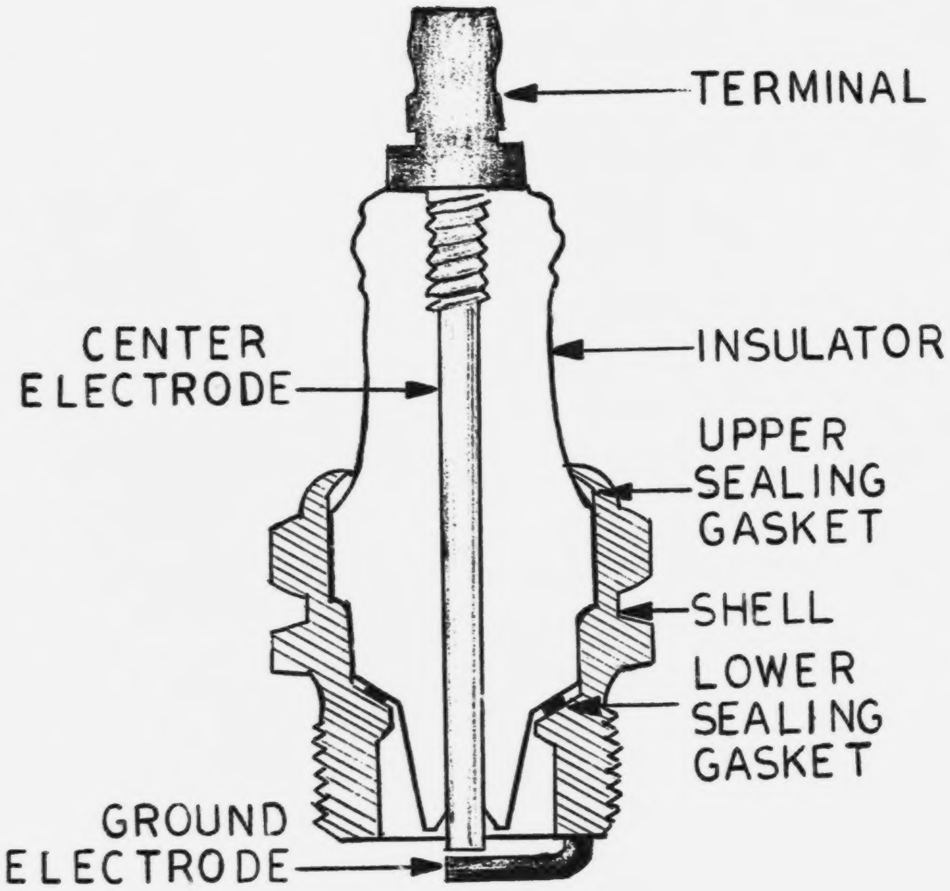
TERMINAL
CENTER ELECTRODE
INSULATOR
UPPER SEALING GASKET
SHELL
LOWER SEALING GASKET
GROUND ELECTRODE

Fig. 1. Sectional view of a spark plug.

principles or would like to become more acquainted with them, you can refer to Sections 217, 223 and 224 in your text — Automotive Mechanics by W.H.Crouse.

The ignition coil has two circuits in it. One is called the primary circuit and the other is called the secondary circuit. The primary circuit is the one which carries the original supply of electricity from the battery. The secondary circuit is the one carrying the high voltage electrical charge produced by the coil (20,000 volts). The primary circuit is made up of a winding of a few hundred turns of a relatively heavy wire wrapped around the outside, but not touching the secondary winding. The secondary winding is made up of many thousands of turns of fine wire wound around a soft iron core.

When current is allowed to flow through the primary circuit, a magnetic field builds up around it. Now if the primary circuit is opened and the current flow stops, the magnetic field around it collapses. Remember how by moving a conductor through a magnetic field, a current was made to flow through the wire? Well, in this case, the wires are not moving, but the magnetic field is. It grows or builds up as the current is turned on in the primary circuit. That is, lines of force start to move out from the wires in the primary circuit. Then when the current is turned off, the lines of force move in toward it. With the coil so constructed that the secondary winding is close enough to the primary circuit that this magnetic field passes back and forth through it, a current is set up in the secondary winding. This current in the secondary winding is of a much lower amperage, but much higher voltage because of the greater numbers of windings in the coil. This voltage is in the vicinity of 20,000 volts.

The operation of the coil depends upon (a) electric current from a lead storage battery; (b) a primary and secondary winding; (c) magnetism; (d) magnetic lines of force produced by one winding inducing voltage in another.

Answers (b) and (c) describe part of the coil construction and principle, but (d) is the correct answer. This is the underlying principle of the ignition coil's construction. As for answer (a), the current can come from anywhere just so that it is of the proper voltage.

The important thing here is to realize that in the ignition coil which is in reality an electric transformer, the current must cause the magnetic field to change direction in order to supply the voltage build-up. This is accomplished by switching it on and off. Turning it on produces the voltage build-up in the primary and turning it off causes a very rapid drop. This causes the direction change of the magnetic field. So what do we need? We need a switch placed somewhere in the primary circuit before it goes to the ignition coil primary winding. Somehow this switch will have to be made to operate at the proper time to provide the high voltage output surge from the coil for the spark plug which is to be fired.

Now the problem boils down to this: How can these 20,000 volts which can be generated be sent to the proper spark plug at the correct instant to ignite the fuel/air mixture in the combustion chamber; and, at the same time, how can the current be turned on and off to transform the battery voltage via the ignition coil to the necessary high voltage for sparking?

Why do we ask these particular questions? First, as was mentioned in the short review of the four-stroke engine, the firing of the cylinders is staggered to provide a smooth power flow. Hence, we have to know which cylinder is loaded with a charge and fire it at that time. Second, the charge should be fired at the proper instant to obtain the most power from the explosion. That is, it must occur neither too early nor too late. Third, while the first two things are happening, the 20,000 volt surge must have been prepared to occur at the same time.

These necessary timing functions are performed by the distributor. That is, the distributor is used to direct the coil output of each high voltage surge to the proper spark plug at the proper instant, and at the same time, to open and close the primary circuit at the required time for producing the high voltage surges.

Before the distributor can direct the coil output to the proper spark plug, it must close the circuit between the battery and primary winding in the coil and then open the same circuit (stop the 6 or 12 volt current flow). This must be done in order to produce the high voltage surge just discussed. When the surge is produced, a rotor in the distributor is under the proper high tension spark plug lead located in the distributor cap. The rotor simply directs the high voltage to the correct spark plug.

The opening and closing of the primary circuit as done in a distributor with contact points will be discussed here. As an example, a six-cylinder engine distributor will be shown (See Fig. 2).

As the distributor shaft rotates, the breaker cam causes the contact points to open and close (our switch), causing the voltage in the coil primary to induce a current in the coil secondary which produces the high voltage. This surge enters the distributor cap and travels through the rotor which is positioned under the proper spark plug lead. Thus, the cylinder containing the compressed fuel/air mixture is ignited.

We're not finished yet. Something has been left out. Notice in the figure that a condenser is shown in the distributor. Why do we need a condenser? To answer this question, we should look at the following.

When the distributor contact points begin to open, the current stops flowing and the magnetic field surrounding the primary winding begins to collapse. The collapsing of the magnetic field produces a self induction in the winding which causes a current to attempt flowing. If the current were allowed to flow, an arc would cross the opening contact points. They would burn and in addition, there would not be a stoppage of current. We want the current to stop as soon as the points begin to open, so that the magnetic field collapses completely. Otherwise, we won't get any voltage induced in the secondary.

Remember that the points are made to separate by the distributor cam. By its forcing the points open and closed, a switch action takes place. Our big concern here is the moment the points are separating. They are still very close together and with the cam movement are quickly forced farther apart. Being so close initially, very little voltage is needed to cause a spark to jump the gap and if not stopped, it would allow current to flow. Something must be done to give the points time to separate enough, so that no spark is possible and current does stop.

If the current generated by the self inductance (i.e. the collapsing magnetic field in the primary tries to force a current within itself) did arc across the points, there would be current flow and the energy from the magnetic field would be used up in the arc; hence, very little voltage would be induced in the secondary. Thus, no spark at the spark plug. So, the current must be stopped. We've got to have a very rapid and complete collapse of the magnetic field to

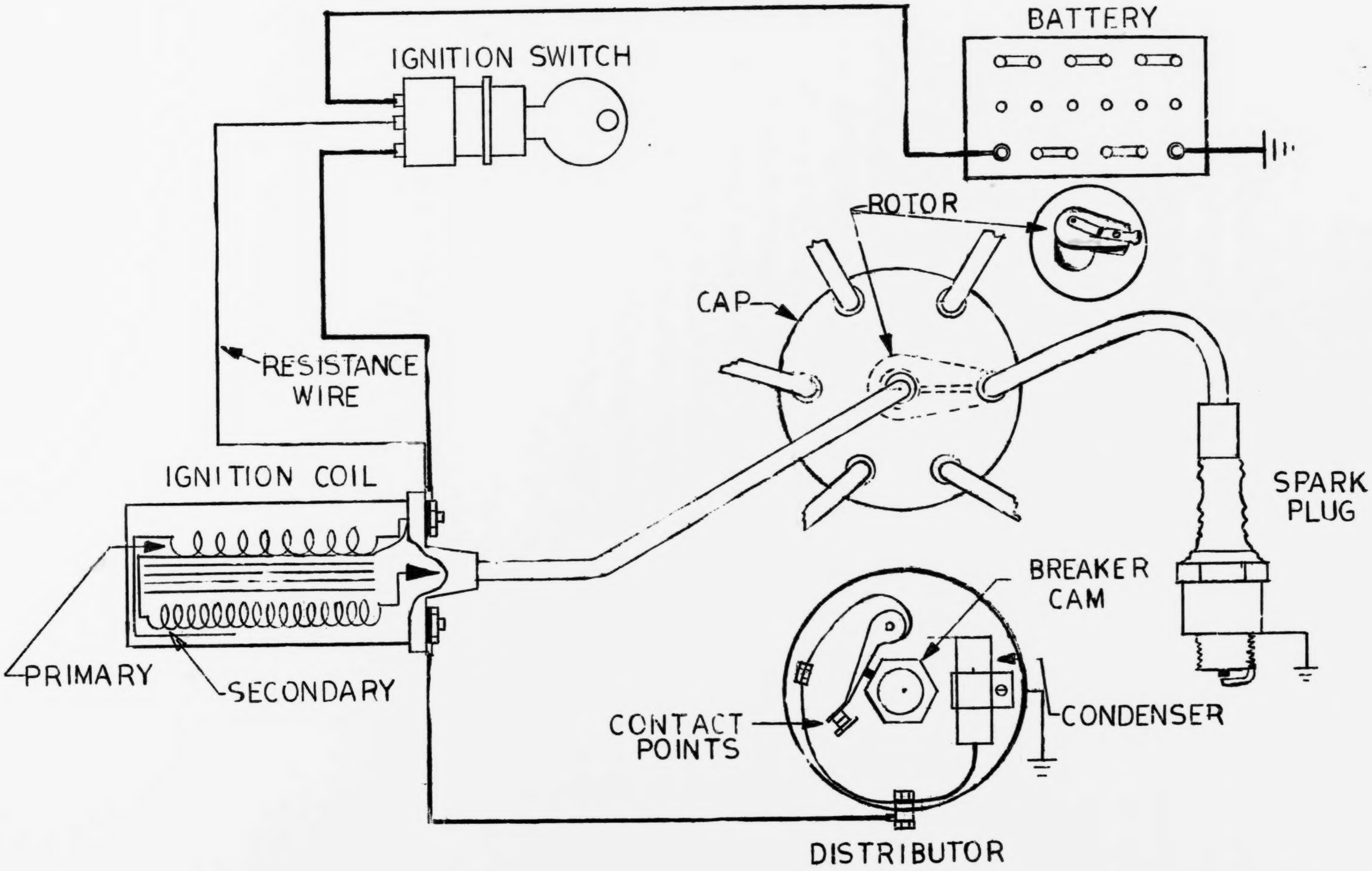
IGNITION SWITCH
BATTERY
ROTOR
CAP
RESISTANCE WIRE
IGNITION COIL
SPARK PLUG
BREAKER CAM
PRIMARY
SECONDARY
CONTACT POINTS
CONDENSER
DISTRIBUTOR

Fig. 2 . A typical ignition system. It consists of the battery (source of power), ignition switch, ignition coil (shown schematically), distributor (with its cap and rotor removed), spark plugs and wiring.

induce voltage in the secondary.

To do this, a condenser, or capacitor as it is sometimes called, is placed in the primary circuit to momentarily absorb this current flow which is attempting to establish itself when the points open.

A condenser is a device which can absorb and store an electrical charge. If we place a condenser in the circuit, then it can absorb the flow of current from the coil primary caused by the self induction. This will help prevent arcing across the points and keep them from burning and stop the current flow in the primary circuit.

The condenser can take only a limited charge and the points are continuing to separate and form a larger and larger gap. Now because the condenser can take a charge, it does, as soon as the points begin to separate, but this rapidly builds up making it more difficult for the current to flow. While the build-up occurred, the points moved far enough apart to prevent any flow in the form of an arc, even though the capacitor became fully charged. It is these two things then: the separating points and the absorption of a charge by the condenser that actually stops the current flow. There is a very small spark which occurs at the contact points at the instant they begin separating, but this cannot be eliminated even with the use of the condenser.

Thus by placing a condenser in the primary circuit to absorb the self induced current, we are able to stop the flow entirely and cause a very rapid collapse of the magnetic field surrounding the primary winding. This collapse is what induces in the secondary winding the voltage which is used to jump the spark plug gap.

Let's look closer at the secondary winding and what happens in it — there are many more windings of fine wire in the secondary as compared to a few windings of fairly heavy wire in the primary. With the rapid collapse of the magnetic field produced by turning off the current flow in the primary circuit, this magnetic field passes across the windings of the secondary. Each turn of the winding will have voltage induced in it. One turn is connected to the other. This amounts to each turn of wire being connected in series and the total of voltages connected in series is their sum. Hence, the secondary winding will produce a voltage equal to the sum of the voltage on each turn.

Are you wondering what happens to the charged condenser? As soon as the points make contact again to close the circuit and cause the next high voltage surge from the ignition coil, the condenser discharges right back into the primary circuit.

To what are we referring when we speak of "necessary timing functions"? What device performs these functions? What operation within the distributor controls the battery current flow to the coil? Which circuit is this, the primary or secondary? What is produced by the primary winding in the coil which induces a voltage in the secondary? Which is more important in causing the high voltage, the magnetic field build up or its collapse?

Try to answer these questions before going on, but don't get yourself all bogged down if you're having any trouble.

If you do feel a little hazy on all this, please complete the section. Then if you feel you don't grasp it all or would simply like to firm it in your mind — re-read this whole section.

B. Components of the Ignition System

1. Ignition Coil

To change the 6 or 12 volts of the car battery to a voltage high enough to jump across a spark plug gap, a transformer (an induction coil usually called the ignition coil) is used. It has two circuits in it, a primary circuit and a secondary circuit. The latter has many thousands of turns of very fine wire. The primary winding is of just a few hundred turns of heavy wire and is usually wound on the outside of the secondary. Both windings are around the same center soft iron core and are separated by an insulating material. The entire unit is sealed into a metal case to which a top of insulating material is attached. This also forms the terminal for the high voltage lead that goes to the distributor.

When current is allowed to flow in the primary circuit, a magnetic field builds up around it and passes through the turns of wire making up the secondary winding. When the current abruptly stops flowing through the primary, the magnetic field surrounding it collapses back in toward it. The lines of force in the field thus pass across the turns of the secondary winding, inducing in it a high voltage. This created high voltage surge is then conducted to a spark plug where it ignites the air/fuel mixture.

The ignition coil is a device which (a) ignites the air/fuel mixture; (b) controls the firing of each cylinder; (c) transforms the battery voltage into a higher voltage for ignition; (d) stops and starts current flow to the spark plug.

The ignition coil is entirely dependent upon outside factors in order to perform. It doesn't control, but rather, its operation is controlled. (c) is the correct answer. As far as (a), (b) and (d) are concerned, the coil is simply one part of a system which performs these operations.

2. Contact Points

Ignition contact points, which are the means for making and breaking the current flow through the primary winding has been discussed in conjunction with the other components in the system. They are made of a very hard and durable metal, usually tungsten, which will withstand high temperatures and wear well. Considering that the points open and close during each power cycle for each cylinder in the engine; on an 8-cylinder engine running at its rated horse power, say 5200 RPM, they would be required to open and close over 20,000 times each minute. We can see, then, that points must withstand considerable wear. Also during operation, the rubbing block on the breaker arm rides against the distributor cam. This block is usually made of a material that is highly durable, but regardless of the materials, the rubbing block wears, causing a decrease in the point gap setting which reduces the dwell angle, which is the same as retarding the timing. Normal wear is to be expected, so it is very important that contact points be checked periodically.

Their function is to start and stop the current flow to the primary winding in the ignition coil. They simply form a switch and are actuated by the distributor cam lobes. The movable point has on it a block which rides on the cam causing the points to open and close the circuit. By opening and closing the primary circuit, they allow the primary winding in the coil to induce a voltage in the secondary winding.

The contact points (a) are made of a hard durable metal; (b) control the flow of electricity to the spark plugs; (c) act as a switch to stop and start current flow to the primary winding in the coil; (d) form an arc between them to allow a current flow.

(a) and (c) are correct. The points are instrumental in providing current to the coil for the high voltage needed at the spark plug, but they do not control the flow of electricity to the plugs; hence, (b) is incorrect. As for (d), a small arc does occur at the points, but only because it cannot be eliminated — it is not desired.

3. Condenser

The automotive condenser is constructed with two plates of conductive material electrically insulated from each other. These plates are really two long, thin narrow strips of either lead or aluminum foil, each having a lead attached, and with the insulating material between each strip wound around an arbor. One plate is connected to the condenser lead and the other to the case.

Constructed as it is, the condenser is able to provide a large conductive area which can accept an electrical charge. Of course, the size of the area limits the amount of charge the condenser can hold.

The condenser is connected across the contact points. The reason it is needed is because of the activity which takes place in the coil. If there were no condenser in the primary circuit, an electrical arc would form across the contact points as they opened. This arc would be formed by the primary winding's self induced current. And if it were permitted to occur, there would not be enough voltage induced in the secondary to jump the spark plug gap besides burning out the points. Hence, the condenser performs simultaneously 1) the job of immediately stopping current flow to effect a rapid collapse of the magnetic field and thus induce a very high voltage in the secondary winding; 2) prolonging the life of the points.

The condenser is an electrical device which (a) condenses the amount of electricity flowing through the points; (b) stops the current flowing to the coil; (c) prevents arcing across the points; (d) aids in stopping the current flow to the coil and reduces arcing across the points.

The answer certainly isn't (a). Do you know what condensed electricity is? (b) and (c) aren't quite correct, but (d) is.

4. Distributor Cap and Rotor

The cap which forms the top of the distributor is made of an insulating material. In addition to covering the top of the distributor, it is formed to serve as the terminals or connections for the high tension wiring. The centrally located terminal receives the high voltage from the coil, while those equally spaced around the outside of the cap connect the distributor to the spark plugs. Located directly below the center terminal is the rotor which rotates with the breaker cam. So when the high voltage from the coil secondary is received at the center terminal, it is passed to the rotor. The rotor is turning in time with the engine, so when it rotates under each of the outer terminals, it passes the high voltage surges from the coil. These surges are directed first to one spark plug and then to another according to the engine firing order.

The rotor used in a distributor (a) rotates on the end of the distributor shaft; (b) is positioned under each spark plug high tension terminal in turn as each high voltage surge is ready to be delivered to a particular plug; (c) forces the breaker point rubbing block which rides on it to open and close the contact points; (d) causes the distributor cap to move back and forth as the spark advance mechanisms change the timing.

The rotor does not open and close the contact points. The distributor cap does not move. It is clamped into a fixed position. Answers (a) and (b) are both correct.

5. Resistor

Many late model cars use a resistor or resistance wire connected in the primary circuit between the ignition switch and the coil primary. Before its function is described, we will discuss some conditions in the ignition system which affect its operation. At low RPM, the ignition points stay closed long enough and allow enough current to flow to establish a good strong spark at the spark plug gap. But as RPM increases, the points are closed for a shorter period, less current flows, and a weaker spark is generated. In other words, the efficiency of the ignition system, as we have studied it so far, decreases rapidly with increasing speed.

To overcome this problem, the resistance wire is placed in the primary circuit as we have already mentioned. The behavior of an electrical resistor is such that the hotter it gets, the higher becomes its resistance which reduces current flow. Also, the opposite is true; the cooler it becomes, the less is its resistance and the greater the current flow. Therefore, at low speeds, the primary circuit current flows through the resistor for a relatively long period causing it to heat up, raising its resistance and reducing the current flow. This action keeps the coil cool and reduces the load of the distributor contact points. At higher speeds, the current flows through the primary circuit for a shorter period allowing the resistor to cool and thus permitting more current to flow. This action increases the secondary voltage at high engine speed where it is needed.

During starting, because of the heavy drain of the starting motor, the resistor is shorted out of the circuit to compensate for the lower battery voltage available. The starting switch and associated circuits are designed to bypass the resistor, thus shorting it out of the circuit during actual cranking.

6. Ignition Distributor

Actually we have been discussing the various components of the distributor all along — the points, cam, rotor and cap. The composite of these parts comprise the distributor itself. Its basic function is two-fold — 1) to open and close the primary circuit and 2) to direct the coil output to the proper spark plug at the right instant. Actually there are two basic types of distributors — the type which uses contact points to open and close the coil primary circuit and the type which uses a magnetic pick-up and a transistor control unit to interrupt the current flow to the coil primary winding. We have spent our time exclusively discussing the distributor with contact points because it is the most widely used ignition system.

The distributor (a) distributes electricity; (b) is a complicated device; (c) stops and starts secondary flow to the coil; (d) is a timing device; (e) controls the current flow to the coil and directs the coil high voltage to the spark plugs.

They are all correct except (c). The distributor does not stop and start the secondary flow. It directs it via the rotor and spark plug high tension leads.

Primary and Secondary Circuits

From all our previous discussions, it should be clear as to why we refer to the ignition system as having a primary and a secondary circuit. The entire primary circuit is that which includes all the circuitry which handles the battery voltage: battery, ignition switch, resistor, points, condenser, the heavy primary coil winding and all associated wiring. The secondary is that which carries the high voltage produced in the coil winding: the fine coil winding, coil high tension lead, rotor, spark plug leads and spark plugs. The primary is actually the first or primary handler of the current in the generation of the high voltage for sparking.

The primary circuit is (a) the first circuit; (b) the most important circuit; (c) less important than the secondary circuit; (d) that part of the ignition system which carries current at battery voltage; (e) carries current used for the production of secondary voltage.

Both (d) and (e) are correct. Answer (a) has some validity in that current flows first through the primary, then a voltage is produced in the secondary via the coil. As for answer (b), who's to say which is more important.

SUMMARY:

Just one more time now; we'll take it from the top. The engine is presumed running. The distributor shaft is being turned. The points are closed. Current flows into the coil primary. The distributor cam is turning; it opens the points. Current from the battery through the coil primary stops. The condenser is charged to prevent arcing and to collapse the magnetic field. The coil secondary has a voltage induced. At the same time the rotor comes under the proper spark plug lead. The high voltage from the coil secondary flows out of the coil high tension lead into the center of the distributor cap into the rotor and out through the proper spark plug lead, through the plug, across the gap and ignites the mixture. The fuel/air mixture burns. The tremendous expansion of the hot gasses forces the piston down and we've initiated a power stroke — swinging!

7. Automatic Spark Control Mechanism

We have shown how a cylinder with a compressed fuel/air mixture can be ignited with up to a 20,000 volt spark from a 6 or 12 volt electrical system and we have emphasized that it must be ignited at the proper instant. But when do we ignite it? What is the proper instant? Exactly when the piston is at TDC (Top Dead Center)? Just before TDC or just after TDC?

In order to decide when to fire the mixture of fuel and air compressed in the cylinder, let's think a little bit about the explosion that takes place. Understanding this, we should be able to determine when to ignite the mixture.

First of all, what is an explosion? Well, according to Webster, it is a sudden bursting, a violent expansion, or the sudden production or release of pressure. What happens when the fuel/air mixture compressed in the cylinder is ignited? It burns very rapidly. A chemical reaction takes place which produces H_2O (water) CO_2 (carbon dioxide) and CO (carbon monoxide). These are the products of combustion. It is the heat resulting from the chemical reaction during the burning of the fuel and air which produces these products that is important to us. (The heat of combustion produces extremely high pressure.) The breakdown of fuel and air and formation of these new products is in the form of an explosion — the mixture burns so rapidly, it is often called an explosion. There is a great deal of heat produced and a tremendous pressure is built up. It is important to realize that it is burning which actually takes place.

The burning takes place from the spark plug gap where the spark occurs out into the rest of the mixture. It is not an instantaneous thing. It takes a certain amount of time for the entire mixture to burn and produce the total pressure obtainable from the mixture. The rate at which the wall of flame travels through the mixture is called the rate of flame propagation. The point we are trying to make here is that we've got to give the mixture time to burn completely if we are to obtain the entire effect of the pressure produced by the explosion.

Now we can answer the questions we asked earlier. In order to get the full force of the hot expanding gas exerted upon the moving piston, enough time must be allowed for it to burn. It will have to be ignited at a point early enough before TDC so that the greatest pressure is produced just past TDC. In order to obtain the greatest effort of the expanding hot gasses, ignition must take place further before TDC as engine speed increases. The mechanisms to provide this are called spark advance mechanisms. These mechanisms vary the spark timing for different engine operating conditions. Because the timing of the spark varies according to the load and speed of the engine, an automatic spark advance mechanism, sensitive to the load and speed of the engine, is incorporated in the distributor. A centrifugal governor advances the position of the distributor cam according to the speed of the engine and a vacuum diaphragm controls the position of the breaker plate assembly according to the load on the engine.

Variable control of ignition timing is necessary because (a) different air/fuel ratios burn at different rates; (b) the rate of flame propagation varies for different mixture ratios; (c) an explosion as it refers to the burning of a compressed air/fuel charge in a cylinder means an instantaneous burning of the entire mixture as opposed to burning with a rapidly propagated flame front; (d) it is necessary to allow enough time for the mixture to burn, depending upon engine speed and load.

Answers (a) and (b) both say the same thing: different mixtures burn at different rates. Because that is true, it is necessary to allow enough time for the mixture to burn — (d). Answer (c) can stand alone as a true statement, but it has little to do with ignition timing as we are concerned with it here.

a. Centrifugal Advance Mechanism

When the engine is idling, the spark is timed to occur just before the piston reaches top dead center (TDC), so that the combustion can be completed by the time the piston reaches a point a little past TDC. At higher engine speeds, there is less time for the mixture to ignite, burn and deliver its power to the piston. Consequently, at higher engine speeds, the spark must be delivered earlier in the cycle. This is accomplished by the centrifugal advance mechanism. It is designed with two governor weights, which through centrifugal force, throw out against spring tension as engine speed increases. This motion is transmitted to the distributor breaker point cam which is advanced in regard to the distributor drive shaft. That is, it is twisted or turned a few degrees ahead of the distributor drive shaft in the same direction of the shaft's rotation. This then causes the contact points to open and close earlier in the compression stroke. Thus as engine speed increases, the spark is made to arrive in the combustion chamber farther ahead of TDC in order to give the mixture time to burn.

Centrifugal advance mechanisms (a) depend upon engine speed to control the spark advance; (b) depend upon manifold vacuum to control spark advance; (c) help out the vacuum advance; (d) cause enormous savings in gas bills.

Even though the vacuum advance and the centrifugal advance both operate together to advance the spark, each is independent of the other. Vacuum advance is dependent upon engine load and centrifugal advance is solely dependent upon engine speed. Therefore, (a) is correct, (c) is not, nor is (b); and (d) is irrelevant.

b. Vacuum Spark Advance Mechanism

Along with the centrifugal spark advance, another method is used to advance ignition spark under load. This is commonly called the vacuum operated spark advance unit. The vacuum advance unit supplements the mechanical advance; however, it operates differently as it varies spark timing in relation to engine load. Engine load can best be determined by manifold vacuum. Under light engine load conditions, there is a high vacuum in the intake manifold caused by the restriction of the partially closed throttle valve; consequently, there is a smaller amount of air/fuel mixture delivered to the combustion chambers. Because the mixture will not burn as rapidly, ignition must take place earlier in the cycle. So consequently the vacuum advance unit mounted on the distributor is connected directly to engine intake manifold vacuum.

The carburetor is used on some applications to control the vacuum operated advance unit located on the distributor. On these units, a calibrated spark advance port is located in the air horn (carburetor bore) just above the carburetor throttle valve. It is connected by a vacuum line directly to the distributor vacuum advance unit.

This unit contains a spring-loaded diaphragm which rotates the breaker plate assembly to advance the spark timing. The diaphragm is connected by a vacuum passageway to the spark advance port which is located above the throttle valve (on the atmospheric side) when the engine is idling. In this position, no vacuum is applied to the diaphragm and the breaker plate is retarded by spring pressure.

In the curb idle position, the throttle valve is below the spark advance port so consequently no vacuum is applied to the advance unit and the spark advance remains in the retarded position. As the throttle valve is opened, it swings past the vacuum port which applies vacuum to the diaphragm, moving it against spring pressure and advancing the breaker plate.

When the engine is accelerated, intake manifold vacuum drops according to the degree of throttle opening which retards the position of the breaker plate assembly accordingly.

Thus, we can see that two things control spark advance. One is engine speed; the other is the load placed upon the engine. The load is determined by how much the throttle is open and how fast the engine is running which determines the amount of air flow through the carburetor. The air flow (determined by air speed) and the throttle opening determine the fuel/air ratio entering the cylinder. Because the fuel/air ratio determines the burning rate, the vacuum advance can be thought of as primarily regulated by throttle opening. And the engine speed regulates the centrifugal advance which is necessary simply because increased engine speed leaves less time for the fuel/air mixture to burn.

Some autos eliminate the centrifugal advance by using in addition to the vacuum spark advance mechanism discussed above, one which also has a vacuum opening at the carburetor venturi. This simply provides vacuum advance in direct relation to the engine speed (the same as a centrifugal advance mechanism).

The spark control mechanisms as we have discussed them here (a) control the intensity of an electrical spark; (b) control the arcing at the distributor contact points; (c) determine the number of times a spark is generated at the spark plug; (d) control the time at which a spark occurs in the cylinder with respect to the piston's position before TDC.

There is only one correct answer here and that is (d). The spark advance mechanisms control the time at which the plug is fired. The spark, as you should know, comes somewhere before the piston reaches TDC on the compression stroke.

8. Spark Plugs

We have discussed, at length, the means of delivering a high voltage surge to the spark plugs in order to produce a spark which can ignite the compressed fuel/air mixture. We've even talked about the spark, but not specifically about the spark plug.

A spark plug's purpose, as we know, is to ignite the fuel/air mixture. Hence, it will be operating under specific conditions and these have been considered in its design. Looking at Fig. 1, you can see the construction of the spark plug. The terminal is where the high tension lead from the distributor is connected. This forms the outer end of the electrode which is encased in a porcelain insulator. The insulator is held in a heavy metal case which is screwed into the cylinder head and makes electrical contact to ground. On the metal case is the ground electrode. It is from the center electrode to the ground electrode that the spark will jump. You can see from the picture that the plug is of heavy and durable construction. It must be to withstand the high pressure and heat developed in the combustion chamber.

Obviously, the heat from combustion will cause the plug to get hot, but it can be so constructed that it will retain more or less of the heat which it picks up. Plugs are referred to as being hot or cold, depending upon their relative retained running temperature.

The heat range of a spark plug is probably the most important factor in its design. Hot operating plugs are constructed with long ceramic insulators, while the cooler plugs have relatively short insulators. The length of the insulator determines the plug heat range because it must pass its heat to the heavy metal case, where it, in turn, passes the heat to the nearby coolant chamber. Therefore, the shorter the conduction path, the cooler the plug operation.

Manufacturers recommend which plug to use for the make, model and year of the automobile and always base their recommendation on average driving conditions. Therefore, it is always important to inspect the spark plugs when they are removed from the engine. An engine driven under severe operating conditions requires cooler running spark plugs than do engines running at continuously low speeds. A plug that is too cool for the operating conditions of the engine will soot up with oil or carbon and will eventually short out. A plug that is too hot will blister and ignite the mixture prematurely by its white hot insulator. A properly operating plug will retain just enough heat to burn off the small amount of oil which is always present in the combustion gasses; the insulator will be relatively clean and have a grayish tan color.

Referring to a spark plug as being a hot plug or a cold plug, (a) is true; (b) is not true; (c) is to make reference to the plug's ability to retain or give off heat; (d) determined by whether or not you can hold it in your hand without getting burned.

Answers (a) and (b) form sentences without any real meaning. Answer (d) might sound good, but that's all. Answer (c) is correct. A cold plug is one which readily passes heat to the surrounding material in the engine head, as compared to a hot plug which retains more heat. It runs at a higher temperature than a similar sized colder plug.

The distance between the center electrode and the ground electrode is referred to as the spark plug gap. And obviously this gap determines the length of the spark. As you will see, the gap is also a compromise when average driving conditions are encountered.

At idle speeds because the mixture is not well distributed and contains a high fuel/air ratio, a long spark is needed for efficient ignition. A long gap provides a smooth idle but reduces top speed. The reason top speed is reduced using a wide plug gap is that higher voltage is required to jump the wider gap and at high speeds, coil output drops off. Hence, a wide gap produces a good idle but poor top speed and a small gap causes a rough idle but increases top engine speed. Therefore, automotive manufacturers specify a gap which is most suitable for all driving ranges. An example of a common gap size is .035 inch for a 1964 Ford Galaxie.

Spark plug gap (a) is the distance between the center electrode and ground electrode; (b) as recommended by a manufacturer is a compromise; (c) is not of great importance; (d) should be as large as it is possible to bend the ground electrode away from the center electrode.

The spark plug gap is certainly very important — (c). A large gap should be used for a good idle and a smaller gap for higher speeds. Therefore, (a) and (b) are correct. The last answer, (d) is absurd.

III. THE FUEL SYSTEM:

A. Purpose of Fuel System

The automotive fuel system has the job of supplying a correctly proportioned mixture of gasoline and air to the engine. This mixture must be varied to suit the requirements of the engine under all operating conditions. During starting, especially in cold weather, when the engine is being cranked, more fuel must be added to the mixture. Gasoline vaporizes slowly in cold weather; therefore, the mixture must be enriched when starting a cold engine. Under such conditions, the mixture of air/fuel ratio is about 9 pounds of air to 1 pound of gasoline. After the engine has been warmed up, the proportion of gasoline in this mixture is reduced to about a 15-17 to 1 ratio. This is about the engine's most economical operating range. However, during acceleration or high speed driving, there is a demand for more power, which requires a richer mixture, reducing the ratio to about 12 pounds of air for each pound of gasoline. These varying conditions are what must be handled by the fuel system.

B. Fuel System Components

The fuel system consists of the fuel tank, fuel pump, filters, carburetor, intake manifold and fuel lines or tubes connecting the tank, pump and carburetor. Details of these components are discussed in the following sections.

1. Fuel Tank

The tank for storing fuel is usually located at the rear of the vehicle. This tank is of sheet metal construction and is held in position by supporting straps attached to the frame. The filler opening of the tank is closed by a removable cap which must be properly vented. The vent in the cap is so designated that air may enter the tank but no fuel can escape. This prevents a vacuum from forming in the fuel tank as the fuel is being used.

The fuel line connection is usually located at or near the bottom of the fuel tank. Most of the later model cars have a filtering element mounted at this fuel line connection. In addition, the tank contains the sending unit of the fuel gauge. Most tanks also have some sort of a vent pipe which allows air to escape when the tank is being filled.

2. Fuel Gauges

There are two basic types of fuel gauge that are used on most automobiles. These are the balancing coil and thermostatic types. Both types are similar in that each has a tank unit and a dash unit. The tank unit has a float which moves up and down in the fuel tank with the fuel level, while the dash unit is simply a gauge which moves over a marked scale from empty to full.

a. Balancing Coil

In the balancing coil system, the tank unit has a sliding contact that slides back and forth on an electrical resistance as the float moves up and down. When the ignition system is turned on, this sends a variable electrical current to the dash unit which causes the gauge pointer to move back and forth indicating the fuel level in the tank.

b. Thermostatic

The thermostatic type also operates from a moving float except that the float lever bends a thermostatic blade which opens and closes the circuit by a set of contact points. When the points are closed, a coil around the blade heats. This causes the blades to open at the contact points and stops the current flow. When the coil cools, the blade bends back, closing the circuit, causing the coil to heat until the pointer opens. This sequence is repeated over and over. The amount of bend in the blade is determined by the fuel level which in turn determines how hot the coil must get before the heat causes the blade to open the contacts.

The dash unit is in the same electrical circuit as the tank unit and when the contact points in the tank unit are closed, current is supplied to the coil in the dash unit. This causes the thermostatic blade to bend which in turn moves the attached gauge pointer.

3. Fuel Tank Lines and Filters

We mentioned earlier that a filter is usually placed in the fuel line connection to the fuel tank. The reason being that water and dirt that accumulate in the fuel tank can cause a clogged or restricted fuel line or filter, malfunction of the vapor discharge valve, fuel pump or carburetor.

Condensation is the greatest source of water entering the fuel tank. It forms from the moisture in the air. When the moist air strikes the cold interior walls of the fuel tank, condensation takes place. If accumulation of sediment in the rear tank filter is excessive, the fuel tank should be removed and flushed and the lines from the fuel pump to the tank should be blown out. Most fuel pumps have a filter incorporated into the unit itself. Also, in later model cars, a separate unit is usually incorporated into the fuel line between the pump and the carburetor. In addition, carburetors often contain filter screens. A restricted fuel tank vent can cause low fuel pump pressure and volume and may, in some instances, result in a collapsed inlet line hose or collapsed fuel tank because of the vacuum created in the fuel tank as the gasoline is used.

4. Fuel Pumps
   a. Single action

Thus far, we have a fuel supply and a means of removing some of the impurities which will probably accumulate. Now, though, we have to get the fuel to the carburetor. Obviously, the fuel pump serves the purpose; but how does it operate? Where does it get its power from? Also, automobile engines don't run at a constant speed; so, therefore, the pump must supply variable amounts of fuel — Right? The pump must then have a variable output, dependent upon the engine demand for fuel.

Fuel pumps are usually mounted on the side of the cylinder block or between the two cylinder banks on some of the V-8 engines. Fuel pumps on in-line engines which are mechanically operated are actuated by means of the fuel pump rocker arm and an eccentric on the cam shaft. On V-8 engines which have the fuel pump mounted between the two banks of cylinders, the rocker arm rests on a push rod. The lower end of the push rod rides on the cam shaft eccentric. The rotating eccentric provides the power to the rocker arm which provides the pumping action.

Other major components of the fuel pump are: 1) a flexible diaphragm mounted between the upper and lower fuel pump housing and attached to the end of the rocker arm assembly inside the fuel pump; 2) the inlet and outlet valves; 3) springs, gaskets and seals; and 4) on most models, a fuel filter. As the cam shaft rotates, the eccentric causes the rocker arm to rock back and forth. The inner end of the rocker arm is linked to a flexible diaphragm which is clamped between the upper and lower pump housings.

On the fuel intake stroke, the cam shaft eccentric causes the rocker arm to force the fuel pump diaphragm to move against the diaphragm spring pressure. The moving diaphragm draws fuel through the intake valve into the pump chamber and automatically closes the outlet valve. Fuel is drawn from the fuel tank through the fuel intake line to replace the fuel drawn into the chamber. Here we can see the need for venting the fuel tank (See Page 23). Air replaces the fuel drained out of the fuel tank.

When the rocker arm moves the diaphragm thus enlarging the chamber, the pressure on the fuel at the pump intake valve is reduced because the movement of the diaphragm tries to form a partial vacuum. That is, it is less than the pressure exerted on the fuel in the tank. Actually, then, it is the air pressure on the fuel in the tank which forces the fuel into the pump chamber through the pump inlet valve because of the greater pressure on the fuel in the tank. If the tank vent were blocked, there would be no pressure difference between the sides of the pump inlet valve when the rocker arm forces the diaphragm to enlarge the chamber and the fuel tank. A partial vacuum would be created in the fuel tank and no fuel would flow.

All fuel drawn into the chamber must first pass through a filter bowl and screen in the line that is usually located on the top or bottom of the fuel pump.

As the cam shaft eccentric continues to rotate, the rocker arm relieves the pressure on the diaphragm spring and allows the spring to push the diaphragm back to its original position which reduces the size of the pump chamber. This action increases pressure on the fuel in the chamber, closing the inlet valve to prevent fuel flowing back to the tank and opening the outlet valve. The fuel is thus forced through the pump outlet to the carburetor.

Fuel is delivered to the carburetor only when the fuel inlet valve in the carburetor is open. The inlet valve in the carburetor float chamber is closed by pressure of the fuel on the float when the specified fuel level in the float chamber is reached. It is the float level in the carburetor which regulates the demand on the fuel pump. When the carburetor float chamber begins to empty, the inlet valve opens and accepts more fuel from the pump.

Let's take a closer look at the fuel pump and see why it doesn't simply supply a constant flow of fuel to the carburetor. The fact that the rocker arm forces the diaphragm to enlarge the pump fuel chamber on the intake stroke was stated earlier. Actually, the rocker arm serves only to lift the diaphragm against the diaphragm spring pressure. When there is no demand for fuel from the carburetor, the diaphragm spring tension is not strong enough to force the diaphragm downward against the pressure built up in the inlet chamber of the pump because the carburetor intake valve is closed by the float. Thus, the up and down rocker action continues, but the diaphragm remains stationary until pressure against the carburetor float is relieved by demand for fuel at the carburetor.

Pressure leak down bleed holes are incorporated in the intake and outlet valve assemblies of all fuel pumps. Also, an air vent is located in the fuel pump body which relieves the air pressure built up on the spring side of the diaphragm.

b. Combination Pumps

A combination pump is a fuel pump with a vacuum pump attached. The fuel pump portion acts the same as just described but has a vacuum unit attached. When power is applied to the rocker arm by the eccentric on the cam shaft, the arm movement pushes the vacuum diaphragm down, expelling the air from below the diaphragm and forcing it into the intake manifold. The same downward stroke enlarges the area above the diaphragm drawing air from the windshield wiper creating a vacuum. As the rotating eccentric moves to its low point, the compressed spring is free to move the diaphragm upward expelling air from above the diaphragm into the crank case. The upward stroke draws air from the wiper into the expanded area below the diaphragm.

When intake manifold pressure is low enough (i.e. when there is enough vacuum) the diaphragm is held near the center of its stroke by the combined effect of the spring pressure and the manifold vacuum. Hence, very little movement of the diaphragm is effected by the rocker arm. Then this vacuum operates the wipers. When the vacuum is not great enough, the rocker arm, as stated earlier, forces the diaphragm down, expelling air into the intake manifold and is able to create enough vacuum to operate the wipers.

c. Electric Fuel Pump

Electric fuel pumps are used on some heavy duty equipment such as trucks and buses. The fuel pump contains a flexible, metal bellows that is operated by an electro-magnet. When the electro-magnet is connected to the battery by turning on the ignition switch, it pulls down the armature and thereby extends the bellows. This produces a vacuum in the bellows. Fuel from the fuel tank enters the bellows through the inlet valve. Then as the armature reaches its lower limit of travel, it opens a set of contact points, this disconnects the electro-magnet from the battery. The return spring, therefore, pushes the armature up and collapses the bellows. This forces fuel from the bellows through the outlet valve into the carburetor. As the armature reaches the upper limit of its travel, it closes the contact, so that the electro-magnet is again energized and pulls the armature down once more. This series of actions is repeated as long as the ignition switch is turned on. The electric fuel pump then supplies fuel to the carburetor on demand from the carburetor, the same as the mechanical pumps, except that instead of being driven by a rocker arm off of a camshaft eccentric, it is actuated by the electro-magnet.

A fuel pump (a) sucks fuel from the fuel tank; (b) develops an internal pressure lower than that on the fuel in the tank which forces fuel to flow; (c) operates the windshield wipers; (d) being actuated by an eccentric on the cam shaft which turns in direct relation to engine speed forces fuel into the carburetor in amounts directly related to engine speed.

Answer (d) is not correct. If you recall, the construction of the fuel pump is such that it delivers fuel to the carburetor only on demand from the carburetor. And how was that done? The float in the carburetor regulates input to the carburetor, and the spring on the fuel pump regulates its output. As for answer (c), only the combination pumps have as one side a vacuum pump which actuates the wiper motor. Today many automobiles have electric wipers. Answer (b) is the most suitable answer; (a) simply refers to the actual pressure difference developed by the pump diaphragm as a sucking action.

5. Carburetors and Carburetion:

The automotive carburetor is an intricate device which must perform automatically over a wide range of engine operating conditions, such as varying engine speeds, load and operating temperature. Its major function is to meter, atomize and distribute an explosive mixture of fuel and air to each combustion chamber. The amount of mixture delivered is regulated by the throttle as controlled by the driver.

The carburetor's relation to the entire fuel system is (a) such, that it is the most intricate device on an engine; (b) the least important part in the fuel system; (c) the last stage of developing in the fuel system; (d) that it is a mixing device.

Answers (a) and (b) are matters of conjecture and opinion, but it is a mixing device — (d). You can consider it the last stage in fuel delivery if you discount the intake manifold and associated intake ports.

To be specific, the carburetion system must supply the engine combustion chambers a mixture of gasoline and air in such a state that it will explode when a spark is put to it. Liquid gasoline doesn't explode, but because gasoline is very volatile, it vaporizes very easily, and when enough vaporizes, any slight spark will set it off. It is the vaporized mixture that explodes, not the liquid gasoline. If you let gasoline sit in a glass for a little while to evaporate, just bring a lighted match, or a lit cigarette near it — it will explode. After the explosion, it will continue burning rather slowly.

What are we getting at here; why does it explode if it is allowed to evaporate? And how does a carburetor "evaporate" enough gasoline into the air quickly enough to cause up to 20,000 explosions per minute. This is what happens in some of today's high power engines. This is what the carburetor provides for. Does it sound like it might be a complicated device? It's not. Especially if we understand what makes it work.

So before we begin to describe the operation of the carburetor, let's take a look at some basic principles to help understand its operation.

a. Atomization

Atomization means breaking the liquid fuel into very small particles, so that it can be rapidly vaporized and mixed with air. In the carburetor, this is accomplished by spraying the liquid into a swiftly moving air stream which dries the liquid fuel (evaporates it) and mixes it thoroughly with the air.

This is what was mentioned earlier. It is quite difficult to get liquid gasoline to burn. It is necessary to vaporize or evaporate it. That is why when we left the glass of gasoline sit for a while, we could have had a minor explosion.

Therefore, we must find a means of quickly evaporating a fair amount of gasoline. How about vaporizing it? Vaporizing the gasoline is to create a fine spray which consists of many fine droplets which can quickly evaporate. To aid vaporization, an air bleed can be provided. By means of an air bleed, some air is admitted into the fuel before it is sprayed out of the nozzle. This helps to break the liquid into a fine mist as it leaves the nozzle. This whole process is referred to as atomization.

b. Metering

Complete combustion demands a correct mixture ratio between fuel and air commonly called the air/fuel ratio. Too much fuel results in what is called a rich mixture, while too little fuel results in a lean mixture. To obtain all possible energy by combustion, the right amount of fuel must be mixed with a given amount of air. The metering job of the carburetor is to furnish the proper air/fuel ratio for all operating conditions, so that engine operation will neither be too lean for power requirements or too rich for economy.

c. Distribution

For good combustion and smooth engine operation, the air and fuel must be thoroughly and uniformly mixed and delivered in equal quantities to each cylinder and evenly distributed within the combustion chamber. Good distribution requires good vaporization. A gaseous mixture will travel much more easily around corners in the manifold and engine. If the fuel is not atomized, the liquid particles being relatively heavy, will try to continue in one direction and will hit the wall of the manifold or travel to another cylinder. To compensate for these problems, manifolds are tailored to the engines to minimize the sharp corners and thus provide as smooth a flow as possible. The carburetor's principal job in distribution is to break up the fuel as finely as possible and furnish a uniformly vaporized mixture in the manifold.

d. Carburetor Fundamentals

We know what we've got to do with the fuel: 1) atomize it (make it burnable); 2) meter it (provide the proper amount of fuel/air mixture); 3) distribute it evenly throughout the incoming air. Of course this all occurs within the carburetor, but how? How do we squirt the gasoline into the incoming air stream to vaporize it? Certainly we know the fuel pump doesn't do this — it simply keeps the float bowl chamber full. But yet this same fuel must be squirted or drawn into the air stream. Let's look at how it might be done.

When you drink through a straw, what actually happens? The liquid in the glass is under atmospheric pressure. Place the straw into it and some liquid comes into the straw — but not higher than the liquid level in the glass — and still under atmospheric pressure. Now put the straw into your mouth and begin to draw on it. What happens is, you lower the pressure in the straw. That is, you create a partial vacuum. There is now a pressure differential between the liquid in the straw and that in the glass. The liquid in the straw has less pressure on it from the air in the straw than does the liquid in the glass which is affected by atmospheric pressure. So what happens? It can't just sit there like this. You know you do drink through a straw.

The greater pressure on the liquid in the glass forces that liquid in the straw up to your mouth. This is the same thing that happened in the fuel pump. When the diaphragm was raised by the rocker arm, it lowered the pressure on that end of the fuel line and the air pressure in the tank forced the fuel into the pump chamber.

Let's give up drinking for a while and get back to mixing fuel with the air flowing through the carburetor. All we've got to do is connect the float chamber to the air passage, create a vacuum in the air flowing through and we'll be able to draw up fuel into the air stream. Can we create a vacuum in air which is at atmospheric pressure? Remember that this atmospheric air is not stagnant; it's flowing. Consider air flowing through a tube. The pressure exerted on all sides of the tube is the same, both inside and out. But if we build a constriction at some point in the tube, the air flowing past this constriction is forced to speed up as it passes through. What happens to the pressure on the inside of the tube at this constriction? Because of the speeding up of the air as it flows past, the air pressure decreases at the restriction.

This constriction in a carburetor is called a venturi (See Fig. 3). So now if our float chamber is connected to the venturi, we will be able to draw fuel from the float chamber which is at atmospheric pressure into the air stream flowing through the venturi.

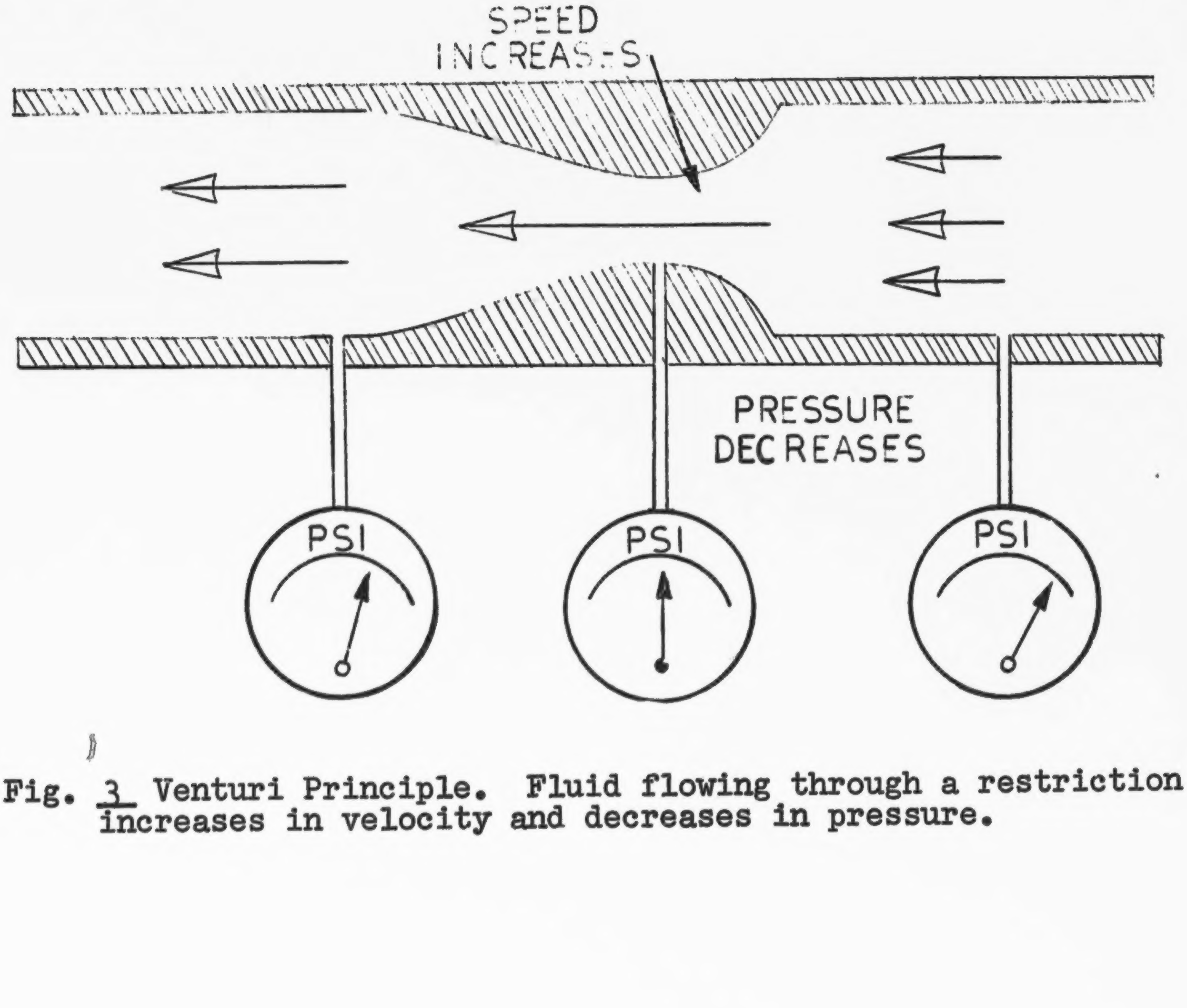
SPEED INCREASES
PRESSURE DECREASES
PSI
PSI
PSI

Fig. 3 Venturi Principle. Fluid flowing through a restriction increases in velocity and decreases in pressure.

The physical principle behind the construction of a carburetor is (a) the float bowl; (b) the main metering circuit; (c) the high pressure created by the swift passage of air through the air horn; (d) the venturi effect.

Well, it isn't (a) or (b); (c) is entirely incorrect, but it is the venturi effect.

Let's consider a very simple device (See Fig. 4) which would perform most of the essential functions of carburetion: A round cylinder containing a constricted section; a pipe entering this cylinder near the most constricted area; and, a round disc placed inside the cylinder which can be rotated to open or close the cylinder. In order to be functional, activation would require a device located at the bottom end of the cylinder able to draw air through it. Also, the opposite end of the pipe we mentioned would have to be extended into a fuel supply. Our simple device now can be considered a carburetor — 1) the round cylinder is the air horn; 2) the constricted section is the venturi; 3) the pipe is the fuel nozzle; 4) the fuel supply is the float bowl; and 5) the movable disc is the throttle valve. Air flow through the air horn would be produced by the intake cylinder action and controlled by the throttle valve.

This simple device utilizes the basic principles which guide the construction and design of an automobile carburetor. In what follows, we'll show how these principles are applied to an actual carburetor.

(1) Vacuum: Carburetors of all types operate on the basic principle of pressure differences or vacuum. Any pressure less than atmospheric is considered a partial vacuum or a low pressure area. In our simple carburetor, we find that as air is being drawn through the cylinder which is called the air horn, it suddenly reaches the venturi where a lower pressure is produced as it passes through this constricted part. Since the fuel nozzle (the pipe in our simple device) is located at this point, fuel is drawn up from the carburetor bowl. This is the same principle as when our drinking straw was used to obtain liquid from a container. The vacuum or venturi action is produced in the mouth. The fuel nozzle is the straw and the glass with the liquid is the carburetor float bowl. Atmospheric pressure on the liquid in the glass is the carburetor float bowl. Atmospheric pressure on the liquid in the glass is greater than that on the discharge end of the straw. The greater pressure on the liquid will force the liquid into the low pressure area (which

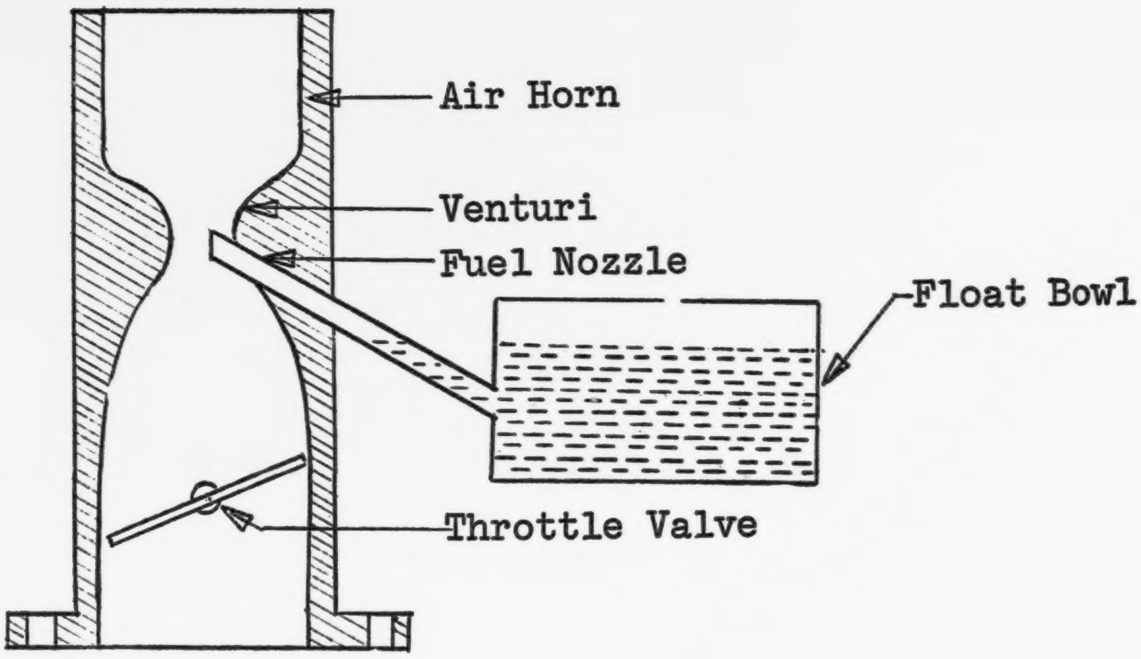
Air Horn
Venturi
Fuel Nozzle
Float Bowl
Throttle Valve

Fig. 4 Simple Carburetor

in this case is the mouth). In our simple carburetor, the higher pressure on the fuel in the float bowl forces fuel up the pipe and out into the passing air.

In our simplified carburetor, we described the air flowing through it and said this flow was produced by the intake cylinder action. We know that the carburetor would be attached to the intake manifold and this in turn is attached to the cylinder intake ports. In the engine, as the piston moves downward on the intake stroke, with the intake valve open, a partial vacuum is created. As the piston moves further downward in the cylinder, there is increased suction or increased vacuum. Outside air forces its way in. This action is what produces the needed air to flow through the carburetor. The fuel and air always move from high to low pressure areas.

(2) Venturi Principle: You remember we called the constricted part of the air horn the venturi? The air horn of the carburetor is the cylinder through which the air flows and contains the venturi. Did you wonder if the size of the venturi limited how much air could be drawn through? If you did, you were on the right track, because it does.

Venturi size is a compromise. The restriction limits the volume of air that may enter an engine which limits the engine's top speed and power. So, the venturi size must be as large as possible. However, at low speeds, where air velocity through the carburetor is relatively low, atomization is very poor with a large venturi. For good low speed performance, the venturi size shall be as small as possible. To help solve this problem, multi-throttled carburetors are being used on many high performance engines.

In four-barrel carburetors, or in triple or dual carburetor installations, the engine is designed to run on two small venturi carburetors during average operating conditions which results in excellent performance and gas mileage. But for the driver who demands power, the secondary side of the quad, or both the front and rear duals of the triple or dual installation open to increase the volume of air/fuel mixture admitted to the engine. Naturally, this increases power tremendously, but lowers gas mileage proportionately.

The venturi effect (a) means that a high pressure develops at the restriction in the air horn; (b) causes atomization to occur; (c) causes a low pressure to occur at the restriction in the air horn; (d) is a lots-a bunk!

The venturi effect is nothing more than the production of a lower pressure at the restricted portion of the carburetor air horn. Answer (a) is incorrect; (b) has to do with an action that does take place in the carburetor but not necessarily due to the venturi effect. (c) is the correct answer. It could be (d), but that depends on how much bunk it takes to make a lots.

At this point, you should have a reasonable idea of the carburetor's function as part of the entire fuel system and how it operates. To briefly review the above discussion, most of the modern carburetors now used on automobiles operate on the principle of pressure differences or vacuum. Air is drawn into the carburetor air horn by manifold vacuum caused by the intake stroke of the pistons. As the air passes through the carburetor on its way into the cylinder, lower pressure is created at the fuel discharge outlets in the venturi section of the carburetor air horn. The fuel bowl is vented to atmospheric air pressure. So the higher air pressure exerted on the fuel in the bowl forces the fuel to travel up through the fuel discharge channels and out into the air stream which is passing through the air horn. Fuel and air are mixed at this point and distributed to the engine cylinders for burning.

If you feel at all hazy on any of the fuel system we've discussed so far, please go back and re-read the necessary sections for a review. Because we are now going to begin discussing the various operating systems within the carburetor in some detail.

e. Basic Carburetor Systems

Because of the variety and complexity of modern carburetors, the carburetor will be broken down and discussed by circuits, rather than by any particular make. Incorporated in most modern carburetors are six basic circuits or systems: float, idle, main metering, power, accelerating pump and choke. The following explanation describes basically how each system operates to provide efficient carburetion for all operating conditions.

(1) Float System

We have seen how the carburetor draws fuel from a reservoir supply. This supply must be maintained at an almost constant level if the carburetor is to operate properly. That is, there must always be enough fuel available for the varying amounts of fuel demanded for all engine operating ranges. When we discussed the fuel pump (See Page 25) it was explained that there was fuel flow to the carburetor from the pump, only on demand from the carburetor. Since fuel in the carburetor float bowl must be maintained at a specified level for correct fuel metering under all driving conditions, let's look at how this is accomplished. The float system accomplishes this by using a float or hollow can which floats on top of the fuel and exerts force against a needle valve. Thus it can shut off fuel flow into the bowl when the specified level is reached. Fuel from the fuel pump enters into the float bowl through the orifice or opening in the fuel inlet (needle valve). As the level in the bowl rises, the buoyant action of the float raises the float, which, in turn, seats the needle in the valve seat, stopping the fuel flow. When fuel is being used from the bowl, the float drops enough to allow the needle to be unseated and fuel will enter past the needle to maintain the level in the float bowl.

Do you remember what action in the fuel pump prevents fuel from being constantly forced into the carburetor float bowl? (See Page 26).

The fuel level controlled by the float setting is an important part of the calibration of the carburetor. If the liquid level is lower than specified, greater than normal air flow will be required through the venturi to lift a given amount of fuel from the float bowl, so the mixture will be lean.

The effects of a lowered fuel level causes poor performance in the main metering system and a definite loss of power. High fuel level can result in premature main metering delivery and fuel spillage during normal car maneuvering, each of which causes excessive fuel consumption and an over-rich condition. The effects of poor main metering will be better understood when this system is discussed.

The float system is perhaps one of the most important systems in the carburetor, as the correct operation of all other systems depends on a fixed level of fuel in the float bowl. So we have a question for you. What action in the float bowl allows the fuel pump to provide fuel only when it needs it?

(2) Idle System

When this section was introduced we briefly talked about the various fuel/air ratios for the different operating conditions. Now we'll see why these mixtures are necessary and how they are maintained.

During engine idle operation, air flow through the carburetor venturi is very low and is not great enough to meter fuel properly from the main discharge nozzle. Therefore, the idle system is used to provide the proper mixture ratios required during engine idling and low speed operation.

The idle system consists of an idle tube, idle passages, idle air bleeds, off-idle discharge ports, idle mixture adjusting needle and the idle mixture needle discharge port. Don't get nervous.

In the idle speed position, the throttle valve is slightly open, allowing a small amount of air to pass between the wall of the carburetor air horn and the edge of the throttle valve. Since there is not enough air flow for venturi action, the fuel is made to flow by the application of vacuum directly through the idle system to the fuel in the carburetor bowl.

This is accomplished by the low pressure below the throttle valve (manifold vacuum) causing the fuel to flow through the idle tube from the float bowl into the idle passage, where it is mixed with air from the air bleed. You recall what is meant by air bleed? (See Page 30). What is the cause of the low pressure below the throttle valve? It is the manifold vacuum. This is the low pressure caused by the suction of the pistons on their intake strokes. (See Page 2). When the pistons move down, they create a partial vacuum which the outside air tries to fill. But the almost closed throttle plate restricts the air flowing past and causes an expansion of the air filling the space created by the piston, producing pressure in the manifold which is less than atmospheric. A partial vacuum is formed -- the manifold vacuum.

The air bleed just mentioned is the first stage of atomizing the fuel. The mixture continues down the idle passage, past the off-idle ports. At this point, these ports act as air bleeds to further break up the mixture because the throttle plate is positioned such that the off-idle ports are still on the atmospheric side. The mixture flows past the mixture screw into the carburetor bore and into the engine intake manifold.

With one end of the idle passage open to this vacuum, the other open to the fuel in the float bowl, and the air bleeds along the way, the difference in air pressure will force fuel into the air stream through the carburetor. The mixture screw controls the idle mixture ratio.

As the throttle valve is opened and allows more air to flow during low speed or off-idle operation, the off-idle ports are exposed to manifold vacuum. At this time, they begin feeding extra fuel for off-idle (slightly higher than idling) requirements. Thus, the off-idle ports have a dual purpose. At idle, they act as air bleeds but during the off-idle range they change to fuel mixture feeds.

(3) Main Metering System

It seems reasonable that if we are able to supply enough fuel for idle and introduce a little more for slightly higher speeds, this isn't going to be enough for cruising speeds. So, we need an additional fuel passage. Besides, we haven't even made use of the venturi effect which we spent so much time discussing.

The main metering system controls the economy range of the carburetor. It consists of a main jet and a main nozzle with air bleeds in it. The main jet is a very accurately machined opening, which controls the fuel flow through the main well in which the main nozzle is located. An air bleed in the main well and the air bleeds in the main nozzle keep the mixture constant throughout the operating range of the main metering system for maximum economy.

The main metering system operates as follows: As the throttle valve is opened, air velocity through the venturi increases, which in turn decreases the pressure in the venturi at the outlets where the main fuel nozzle is located. This will cause the fuel to be pushed by external pressure through the main metering jet and up the main nozzle. As the solid fuel enters the nozzle, it is mixed with air through the calibrated (air bleed) holes in the nozzle. This air aids in atomizing the air/fuel mixture for improved distribution. The mixture continues through the passage and enters the air stream at the venturi. At this point, it is mixed with the incoming air and is carried past the throttle valve and into the manifold for distribution to the engine cylinders. The venturi principle is used over the widest range of engine operation.

Main metering provides a proper and economical fuel/air ratio for cruising and normal load conditions, approximately 14-17 lbs. air to 1 lb.

fuel. But if load on the engine increases and maximum engine power is required, all air available for combustion must be used. By simply adding more fuel to the air, the fuel/air mixture can be increased to approximately 12-14 lbs. of air to 1 lb. of fuel. This produces the most power from the burning mixture in the cylinder, which in turn produces the maximum engine power.

(4) Power System

The power system consists of a spring-loaded piston, a vacuum passage to the intake manifold, a valve and a restriction between the valve and the main well. The piston determines when the valve opens and the restriction determines how much fuel will be added to the main well in addition to what the main jet is already supplying.

The power system, controlled by manifold vacuum, provides an additional fuel inlet to the main nozzle under low vacuum conditions. Normally, the piston is held up by high manifold vacuum but any time manifold vacuum falls below the tension of the piston spring, the spring tension forces the piston down, opening the valve to increase the fuel flow to the main nozzle. This sytem is operative only when the engine demands enrichment for extra power.

Why is manifold vacuum used to control the lifting of the power piston to provide additional fuel flow to the existing air supply? Recall the explanation of manifold vacuum (See Page 33) ? When the engine is running at normal operating speed and only the main metering system is supplying fuel, the rate of air flowing is determined by throttle position and how much air the pistons are able to pull in on their intake strokes. This results in a fairly high manifold vacuum (usually above 10" of mercury). What determines load on the engine? Well, if the throttle plate is opened all the way and the engine continues running at the same speed, this allows more air to enter the intake manifold because the throttle is no longer restricting air flow. What results? There is more air now in the intake manifold and hence the manifold vacuum decreases. There is less pressure difference between the atmospheric air and that flowing through the intake manifold. Referring back to the explanation of the power system, we see that the vacuum no longer holds up the piston against the spring pressure and the valve is opened. This allows fuel to flow which in turn enriches the air/fuel mixture producing more power from the engine even though engine speed doesn't increase.

An example of this situation occurs when the car begins climbing a hill. Think about the last time you were driving along on the level and then began to ascend a hill. As you began to ascend, to keep the car at the same speed, you began to step on the throttle pedal and maintained your original speed. You also heard the engine noise change pitch and get louder. This was the result of the power system cutting in and providing more power in the cylinders.

The power circuit within the carburetor (a) uses a great deal of the available engine power output; (b) produces power; (c) enables the transmission to down-shift when necessary; (d) lowers the air/fuel ratio (richen the mixture) during engine load.

Answer (d) is correct. When engine intake manifold vacuum drops below a specified amount, the power valve opens, allowing more fuel into the air stream (richen the mixture) thus allowing each combustion to produce greater force. The power circuit only richens the mixture; the engine produces more power. Therefore, answers (a), (b) and (c) are not correct.

(5) Pump System

When the throttle is opened rapidly, the air flow and manifold vacuum change almost instantly. Because of the great difference in weight between air and fuel, any sudden change in throttle opening results in an immediate increase in air intake, but the fuel, having greater weight tends to lag behind. The result of this is momentary leanness.

Sudden leanness would cause the car to balk or jerk, or suddenly loose power. You don't want this to happen. When you tramp the throttle pedal very quickly, you do it for a reason — you want a quick surge of power. This is actually what does happen. You know that the car doesn't momentarily slow down (if it's operating properly). So let's look and see what enables the carburetor to provide a proper air/fuel mixture when the throttle plate is suddenly opened and you get the required surge of power.

The accelerator pump, located in the carburetor float bowl, provides the extra fuel necessary to overcome the leanness of the fuel/air mixture and give smooth operation on all throttle openings. This is accomplished by discharging extra fuel into the venturi air stream whenever the throttle valve is opened quickly. The pump system utilizes a pump plunger that is linked to the throttle lever by mechanical linkage. Any opening of the throttle valve causes the pump plunger to move downwards in the pump well. This action forces fuel through the pump passages and out the pump jets into the incoming air stream. As the throttle is closed, the pump plunger is lifted up in the well, creating a low pressure below the plunger. An inlet ball check is lifted off its seat and allows fuel to flow into the pump well. At the same time, a discharge ball check seats to prevent air from leaking into the discharge passage. A duration spring and return spring work together to give a controlled, smooth discharge for a moment after the accelerator pedal stops moving.

(6) Choke System

Do you remember the very first paragraph? We said when the engine is cold and is being cranked for starting, a very rich air/fuel mixture is needed. None of the carburetor circuits we've discussed so far enable us to control enriching the mixture enough for starting. To eliminate the need for a rich starting mixture, we could warm the engine so we don't need it. Right? The problem would be solved. You could keep it wrapped in a blanket or maybe sit on it for a while. Now who goes out, especially in the winter, and warms the engine block before he starts his car? As an alternative, why not try to restrict the flow of air which enters the intake to the carburetor air horn? If we do this and considering the way the idle and off-idle circuits are set up, restricting the air intake will draw the normal amount of fuel into less air, thereby providing a richer air/fuel mixture. The restricting device is a round plate just like the throttle plate but at the top of the carburetor and is called the choke. This plate can be opened or closed as is necessary to control the air flow.

The purpose of the choke system then is to provide a richer mixture for cold engine starting and operating. Mixture enrichment is necessary because fuel vapor has a tendency to condense on cold engine parts, such as the inside area of the intake manifold and cylinder head, thereby decreasing the amount of combustible mixture available in the engine cylinder.

In the automatic choke carburetor, when the engine is cold, a thermostatic coil holds the choke valve closed. This cuts down the air supply and raises the vacuum applied to the fuel outlets, so that more than the usual amount of fuel may be drawn into the cold engine.

As the engine warms up, the manifold vacuum supplied to the choke housing pulls hot air from the exhaust manifold through a passage in the choke housing to heat the thermostatic coil. The thermostatic coil relaxes gradually until the choke valve is fully opened. A choke piston is used as an aid to offset tension of the thermostatic coil and to open the choke valve.

Some older and foreign cars have a hand choke, the setting of which is controlled by the driver.

Since a cold engine requires a richer mixture during starting than a warmed engine, most cars have (a) an electric blanket to warm the engine to normal operating temperature in order to eliminate the problem of supplying a richer mixture; (b) a supply of ether aerosol cans; (c) a choke; (d) a device to restrict the carburetor intake air flow which increases the fuel/air ratio (richens it).

Electric blankets aren't very efficient as engine warmers, and ether aerosol spray does help. But all cars do have some form of choke to provide a richer mixture. Therefore, (c) and (d) are correct. A choke is what is described by answer (d).

6. Air Cleaner

All automotive engines are equipped with some sort of a cleaner for filtering all of the air entering the engine. This device acts as a flame arrester in the event of an engine backfire and also as an air flow noise silencer. It should be noted that tremendous amounts of air enter the air horn of the carburetor. Under a normal operation range when the air/fuel ratio is about 15 to 1, this would be about 1200 cubic feet or 9,000 gallons of air per gallon of gasoline. Also, this air is obtained from the atmosphere under all types of operating conditions, so is likely to contain a great amount of floating dust and grit. The grit and dust could, if allowed to enter the engine, cause serious engine damage. Therefore, an air cleaner is mounted on the air horn or air entrance of the carburetor to keep out the dirt and the grit. All air entering the engine through the carburetor must pass first through the air cleaner. The two most commonly used air cleaners are the dry type and the oil bath. There is also a type which is essentially a combination of the two which uses a ring of polyurethane material, saturated in oil. Essentially, they are similar in design and perform the same function. We will only discuss the dry and oil bath type.

a. Dry Type

Air from the engine compartment enters the dry type air cleaner assembly through the opening or horn on the side of the assembly body. This type has a filter element made of material usually containing fine mesh metal threads or special paper. All air must pass through this element. After passing through the filter element, the air flows down into the carburetor. Dust particles and other foreign materials are trapped in the filter element as the air rushes through it.

The dry type filter element must never be cleaned with a solvent or cleaning solution. Also, oil must not be added to the surfaces of the filter element or air cleaner body. Usually this type of filter is replaced after a specified number of miles, depending upon the engine operating conditions.

b. Oil Bath Type

The air from the engine compartment enters the air cleaner and passes down through the outside wall of the filter element and the wall of the oil reservoir. The air is then deflected by a baffle in the bottom of the oil chamber up through the filter element. After passing through the filter element, air flows into the carburetor. As the air rushes across the oil in the filter, large heavy particles fall into the oil and are entrapped. The smaller dust particles are trapped in the oil dampened filtering element as the air passes through on the way to the carburetor.

An air cleaner is used on the carburetor air intake (a) to remove allergenic pollens from the air; (b) to remove dust particles from the air; (c) because nobody likes to breathe unclean air; (d) to prevent back-firing up through the carburetor.

Its primary purpose is to remove dust particles from the air being pulled into the engine. If some of these are pollens large enough to be trapped, they too are removed from the intake air. We don't really care. Few engines suffer from allergies. Answer (d) is also correct; (c) is probably true, but we're not concerned here with what people like to breathe.

7. Intake Manifold

We've already discussed some of the things which happen in the intake manifold for carburetor operation. We would like to mention the manifold here as a specific part of the fuel system.

The intake manifold is essentially that portion of the fuel system which delivers the combustible mixture of air and fuel from the carburetor to the engine combustion chamber. This is accomplished by a specifically designed tube or series of tubes extending from the carburetor to the various engine intake valve ports. Since the power developed by a gasoline engine can be regulated entirely by the air it breathes, the fuel induction system performs a very important role. The intake manifold is a major part of the system and is often overlooked in engine diagnosis and tune-up.

The intake manifold is (a) the device which pulls air into the engine; (b) forms the channel which directs the air/fuel mixture from the carburetor to the cylinder intake ports; (c) where vacuum is obtained to operate the valve in the power circuit; (d) not to be found on a diesel engine.

Answer (d) is irrevelant here, but does form an incorrect statement. The manifold does not pull the air/fuel mixture in. It is as described by both (b) and (c).

C. Operational Combustion Requirements

As has been discussed, the fuel system must vary the air/fuel ratio to suit different operating requirements. Graphic evidence is available as to when these variations must occur. The unfortunate part is that this information is valid only for the engine for which it was designed; so it cannot be used for a different car. For our purposes here, we will show a generalized graph in order to illustrate these variations.

1. Air/Fuel Ratio vs. Miles Per Hour

The carburetor fuel curve is a graphic description of air and fuel requirements of an engine in all ranges of operation. For economy, sufficient air must be supplied to burn every particle of fuel, and for power requirements, additional fuel must be provided to use all of the available air.

Under normal conditions, the air/fuel ratio requirements for gasoline engines will vary from approximately 9 pounds of air to one pound of fuel all the way to 20 pounds of air to one pound of fuel. Economy mixtures normally range from about 14 to 17 pounds of air to one pound of fuel. When more engine power is applied, the mixture will decrease to about 12 to 14 pounds of air to one pound of fuel.

A typical flow curve (See Fig. 5) shows the speed in miles per hour across the bottom of the chart and the mixture ratio scale up the side. At curb idle, about 0.5 pounds of air per minute is flowing with an air/fuel ratio of 9 to one. This is the richest point on the curve. Idle air/fuel ratios are always rich due to low engine speed which creates low air velocity and poor scavenging of exhaust gasses from the cylinder which causes dilution of the fresh charge of fuel and air entering the cylinder. Also, vaporization and distribution in the intake manifold under idle conditions are relatively inefficient. Therefore, rich mixtures are necessary to cover up these deficiencies and insure sufficient fuel to all cylinders for a smooth idle.

As the throttle valve opens, air flow increases and the engine works more efficiently allowing use of leaner mixtures. This is noted on the chart by the sharp drop in the curve starting at approximately 20 MPH and then flattening out into the economy range with a ratio of 15 to 16 to one in the 40 - 60 MPH ranges. At this point, the air flow is about 12 pounds per minute. When the curve richens to 13 to 14 to one, about 15 pounds of air per minute is going through the carburetor and maximum power is attained. This represents wide open throttle and maximum engine speed. Beyond this point, no further increase in air flow is possible and if the engine load is increased, the speed will gradually diminish. If engine load is continued, air flow will start to diminish as engine speed decreases and will eventually reach a point where the main metering ceases and results in a lean engine stall-out. The flow chart shows the delivery characteristics for a typical carburetor on a six-cylinder engine. The size, type of engine, and operating conditions affecting fuel consumption all determine the specific air/fuel ratio.

The carburetor circuit which utilizes the venturi effect is the (a) float bowl; (b) idle and off-idle; (c) main metering; (d) accelerator pump.

The venturi effect causes a low pressure in the restricted portion

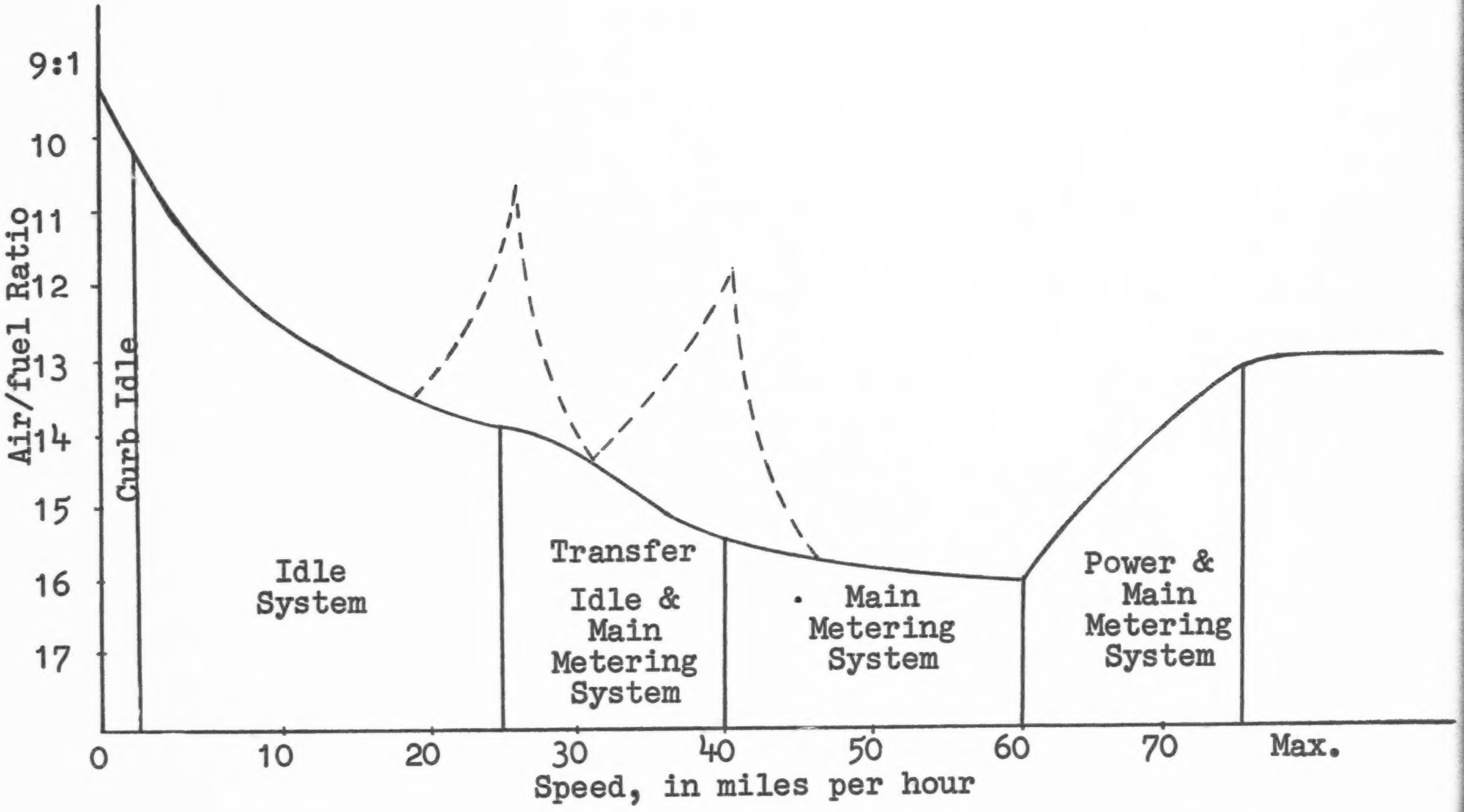

Fig. 5 Typical air/fuel ratio for different automobile speeds.

of the carburetor air horn and if a tube is placed with one end in the venturi and the other in a fuel supply at atmospheric pressure, the higher pressure on the fuel will force it through the tube. This is in effect the main metering circuit — answer (c). Answer (a), (b) and (d) do not apply.

2. Carburetor System vs. Miles Per Hour

The flow curve (See Fig. 5) also shows the approximate speed at which the various carburetor systems may operate. The idle system functions alone up to approximately 25 miles per hour. Between 25 to 40 miles per hour, the mixture is supplied by the main metering system and will continue until the manifold vacuum drops below a pre-determined point. At this point, the power system comes into operation. These speeds are approximate; but they may be used as a guide in troubleshooting to decide which system is at fault for a given complaint.

There are two dotted lines on the chart which we have not explained. These are points of acceleration occurring at about 20 and 30 miles per hour and are an indication of action by either the power valve and/or accelerator pump circuits. The acceleration points are shown only for purposes of illustration. In actuality, they may occur anywhere in the speed range.

As was discussed in the power and pump systems, any rapid opening of the throttle or demand for more power changes the air flow and manifold pressure almost instantly. Fuel being much heavier does not increase in flow nearly as fast, causing a momentary leanness. To compensate for these changes, rapid acceleration actuates the pump system linked directly to the throttle lever, thus discharging extra fuel directly into the venturi stream. This enriches the mixture and overcomes the momentary leanness thus producing rapid acceleration. Also, the power circuit controlled by the manifold vacuum provides additional fuel to the main nozzle under low vacuum conditions. This system is operative only when the engine demands extra power; so it starts cutting out when manifold vacuum increases, and control returns to the main metering circuit.

Again, remember that this graph is for explanatory purposes to illustrate the general principle and does not necessarily represent any one type of carburetor during actual driving conditions.

The main metering circuit depends upon the lowered pressure developed at the venturi section to draw fuel up the main nozzle and out into the air stream. This system operates through the engine speed range of (a) idle to 20 mph; (b) approximately 20 - 40 mph; (c) approximately 25 - top speed; (d) all speed ranges.

We know that a carburetor has an idle — and off idle circuit built in because at low speeds, there isn't enough air flow to operate the main metering circuit. And once a speed is reached which will operate, the main meter circuit does start operating, it continues to top speed. Therefore, answers (a), (b) and (d) are not correct.

IV. ENGINE ANALYSIS:

It is necessary to diagnose an engine's running characteristics in order to determine any trouble which may be preventing it from achieving optimum performance — troubleshooting in other words.

Troubleshooting is done before a unit is disassembled so that the mechanic can give the car owner an estimate of the cost of the repair job. It helps the mechanic pinpoint the trouble, so he will know what to look for when the unit is being disassembled. Troubleshooting will usually cut down on the amount of time spent on repair, provided the defective section can be pinpointed with some degree of accuracy.

Actually, there is no substitute for accurate equipment. However, there are times when a quick test is needed to localize trouble which saves the time of hooking up a battery of test equipment. Besides saving time, developing familiarity with the various testing possibilities, results in a depth of understanding that enables a mechanic to do a better job and a quicker one.

There are also times when a mechanic is called on to locate troubles under somewhat less than ideal conditions. This happens when he is sent to start a car stalled at some distance from the garage. Naturally, he cannot carry all the specialized test equipment with him. He has to depend on some rather simple tests to locate the trouble in order to start the engine. When the car is brought back to the garage, then he can use whatever accurate equipment is available to check further and make the necessary repairs which caused the original breakdown.

The first troubleshooting we will consider will be concerned with starting troubles. These first tests will be concerned with determining the defective system: Cranking, Ignition, Carburetion or Compression. As soon as the defective system is isolated, it is necessary to begin more detailed diagnosis to determine the specific fault. We will present here, first, the four tests which will enable isolating the defective system; and then detailed tests will be described which can be used for each system to enable pinpointing the defect. (When you are actually performing a diagnosis, you obviously will not test systems you know to be o.k.)

A. Basic Starting Trouble Tests

When an engine is difficult to start, or does not start at all, it is necessary to use logical procedures to locate the trouble. Basically, the problem of hard starting can be broken down into four areas of trouble: Cranking, Ignition, Fuel and Compression. Tests are usually made in this order. When the trouble is localized to one of these four areas, you can then proceed to make one of the more detailed tests.

1. Cranking System

Turn on the ignition switch and energize the starting motor. If the starter motor cranks the engine at normal speed, it is an indication that battery cable, starting switch and starting motor are in good shape. A defective cranking system is evidenced by failure of the cranking motor to spin the engine at a normal rate of speed. If the cranking system is operating satisfactorily, go on to the second test, the ignition system. Otherwise, proceed to the more detailed system of the cranking system.

2. Ignition System

Disconnect one spark plug wire. Check the spark intensity at the end of the wire by installing a terminal adapter in the terminal. Hold the adapter about $\frac{1}{4}$" from the exhaust manifold while cranking the engine with the ignition switch turned on. A good constantly occurring spark indicates that the ignition system is in good shape. No spark, a weak spark or an irregularly-occurring one means ignition trouble. If the ignition system is operating satisfactorily, go on to the third test, the fuel system. Otherwise, proceed to the more detailed test of the ignition system to isolate the trouble.

3. Fuel System

Remove the air cleaner to uncover the carburetor throat. Then open and close the throttle several times. A stream of fuel will be discharged from the accelerating jet if the fuel system is in good shape. You recall that the accelerating jet is actuated by sudden throttle opening, regardless of air flow through the carburetor.

Hard starting might also be caused by engine flooding if too much fuel has been discharged by the accelerating pump circuit. If this is the case, this can be cleaned by full depression of the accelerator pedal while cranking the engine. This actuates the carburetor unloader linkage, permitting air to enter and dry out the intake manifold and combustion chambers.

No fuel discharge indicates that there is probably no fuel in the carburetor which means trouble in the fuel delivery system. In rare instances, the carburetor accelerating system may be defective and no fuel will be discharged, even though the carburetor is full of gasoline. If the fuel system is operating satisfactorily, go on to the fourth test, compression. Otherwise, proceed to the more detailed test of the fuel system to isolate the trouble.

4. Compression

Failure of an engine to start due to compression is rarely encountered in the field. Most frequently, compression troubles will show up as a defect in one or two cylinders. No compression in all cylinders of the engine may occur from improper mating of the timing gears when the engine is rebuilt. It can happen on the road through jumping of a loose timing chain or the snapping of a cam shaft, but this is so infrequently the case that it is not often the condition causing starting trouble.

Compression can be checked by removing a spark plug and holding your thumb over the spark plug hole while the engine is being cranked. Good compression produces a distinct pressure under your thumb, as the piston rises to the top of the stroke.

B. Detailed Tests for Hard Starting

The more detailed tests which follow are to isolate the starting trouble in the defective system located by the first series of tests. Each of the four general areas of possible trouble is broken down further to test the individual components. In this manner, the exact part or parts causing the trouble can be located and replaced.

1. Cranking System

The test of the cranking system is the same as for emergency troubleshooting. Failure of the starting motor to spin the engine, or turning it too slow, is an indication of a defect in one of the major components in the system. Once this has been determined, a more detailed testing procedure should be followed for diagnosing the exact location of the malfunctioning component(s).

a. Battery (Test 1).

The battery supplies electric current for the starting motor, lights, ignition and other electrical accessories. If the starting motor spins the engine at a fairly good rate of speed and then rapidly slows down, the battery is discharged. Turn on the lights while cranking the engine. If the lights go out, the battery is discharged because there is not enough current in a partially-charged battery to supply both the starting motor and the lighting system.

A six-volt battery with a defective cell (shorted separator) usually will not turn the starting motor at all, although it may do so for a very short period of time if the battery has been charged by a recent run of the engine. If such a battery is allowed to stand for a short time, it will lose this surface charge. A twelve-volt battery may operate the starting motor with a defective cell, but it will not spin the starting motor fast enough and starting troubles will result.

b. Battery Cables (Test 2).

Quite frequently, a bad connection between the battery post and the battery cable will show up as a dead battery. To check this condition, insert a screwdriver blade between the battery post and the cable while having an assistant operate the starting motor switch. Try the blade on each terminal connection. Now, if the starting motor turns, evidently the connection is bad. It should be cleaned by removing the cable terminal and scraping it and the battery post until clean metal appears. Then replace and tighten the terminal securely.

c. Switches (Test 3).

A defective switch in the starting circuit can be checked by bridging each switch in turn with a jumper wire. Bridging the solenoid switch bypasses all other control switches and should energize the starting motor regardless of any other defect in the starting motor control circuit. CAUTION: Use a heavy piece of wire for this test, as a thin one will become very hot from the large amount of current drawn through this circuit. Holding a hot wire may cause a serious skin burn on the hand.

If the starting motor does not operate with the solenoid switch shorted and the battery fully charged, then the trouble must be in the starting motor itself.

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d. Starting Motor (Test 4).

The size of the spark across the jumper wire in the previous test is an indication of the kind of trouble to be expected. If there is a heavy spark and the starting motor does not turn, it is possible that the starting motor is stuck to the flywheel; the starting motor has a short circuit; or there is a hydrostatic lock in the engine (when water from the cooling system fills the cylinder, preventing a compression stroke).

If there is little or no spark as the jumper wire is moved across the solenoid switch terminals, there is an open circuit present with little or no electricity flowing. This condition can be caused by a dead battery, a poor battery terminal connection (which should have been determined by Tests 1 & 2) or poor connections at the starting motor brushes, due to a burned commutator or one with oil on it. If the starting motor spins but does not crank the engine, the starting motor drive is defective.

2. Ignition System

The ignition system furnishes the electric spark which fires the mixture. Absence of a spark, or a weak spark, will cause starting trouble. Ignition troubles should be isolated by logical testing. For this purpose, the system is broken down into its smaller circuits, the primary and secondary. Each of these should be broken down further and individual components tested separately.

a. To Test the Entire Ignition System

Remove one spark plug wire and hold it about $\frac{1}{4}$" away from the base of the spark plug or any metallic part of the engine. Crank the engine with the ignition switch turned on. A good spark from the wire to the metal means that the entire ignition system is in good working order and none of the following tests need be made. (This should have been determined with the basic test.) No spark, or a weak, irregularly occurring spark, means ignition trouble which must be traced by means of the following tests:

b. To Test the Primary Circuit (Test 1).

Loosen the distributor cap retaining bails and move the cap to one side. Remove the rotor. Turn the engine over by means of the fan belt or starting motor (you shouldn't be here if the starting motor wasn't working) until the contact points close. Turn on the ignition switch. Remove the high tension wire leading to the center of the distributor cap; this is the main wire from the ignition coil which supplies the high voltage to the rotor for distribution to the spark plugs. Hold this wire about $\frac{1}{2}$" from any metallic part of the engine. Open and close the contact points with a screwdriver by pressing against the movable point only. What will happen by your opening and closing the points in this manner? You are allowing a current to flow in the primary winding of the coil, shutting it off, and thus producing the high voltage surge from the secondary. We discussed this in Section II, The Ignition System. A good, regularly occurring spark from the high tension wire to ground means a good primary circuit and a good ignition coil. No spark, or a weak erratic one, from the high tension wire to ground means primary circuit trouble or a bad ignition coil. We are unable to determine which it is at this point. Before the secondary circuit is tested, we should first establish confidence in the primary.

c. To Test the Ignition Contact Points (Test 2).

To test the condition of the ignition contact set, turn the engine over with the fan belt or starting motor until the contact points are separated. Slide the screwdriver blade up and down, making contact between the movable point and the bottom plate of the distributor. You are now using the screwdriver tip and the bottom plate of the distributor as a set of contact points. A good spark from the high tension wire to the ground, after having had no spark in Test 1, means that you have a defective set of contact points. No spark, or a weak one, means primary circuit trouble, other than the ignition contact points, or a bad ignition coil.

d. To Test the Condenser (Test 3).

A shorted condenser can be checked by noting in the previous ignition contact point test whether or not the tip of the screwdriver blade sparked against the ground plate as it was slid up and down. No spark at the tip of the blade means either a shorted condenser or a break in the primary circuit.

This can be checked further by disconnecting the condenser case where it is screwed to the distributor (do not disconnect the condenser wire lead). Hold the condenser so that its case does not make contact with any metallic part of the distributor. Repeat the test of moving the screwdriver blade up and down while holding it against the movable point. Be sure that the contact points are open while making this test. A spark at the screwdriver tip now, which was not present with the condenser in the circuit, means that there is either an open circuit somewhere in the primary circuit or the condenser is shorted out. Check the small wire lead from the primary terminal to the movable contact point. This wire lead sometimes parts under the constant flexing of operation.

e. To Test the Secondary Circuit (Test 4).

The secondary circuit cannot be tested until the primary circuit is functioning properly. If the primary circuit tests good, or after the necessary repairs have been made to the primary circuit, then the secondary circuit can be tested.

To test the secondary circuit, turn the engine over until the contact points close. Then turn on the ignition switch. Hold the main high tension wire (from the center terminal of the distributor cap) about $\frac{1}{2}$" from any metallic part of the engine. Open and close the contact points with a screwdriver blade held against the movable contact point only. No spark, or a weak one, from the wire to the block means a bad ignition coil or a defective main high tension wire from the coil to the distributor (especially where it runs through metal conduit). At this point, we can be sure the trouble is here because we know the primary circuit is good. A good spark here (with no spark to the spark plugs) means that the trouble must be in the distributor cap, rotor, or spark plugs. It is seldom that spark plug high tension wires (unless obviously rotted) will keep an engine from starting. To check the main high tension wire from the coil to the center of the distributor cap, replace it with a new piece of high tension wire, or remove the old wire from the metal conduit (if it is encased) and repeat Test 4 while keeping the suspected wire away from any grounded surface.

f. To Test the Distributor Rotor (Test 5).

Test the distributor rotor by replacing it on the distributor shaft and holding the main high tension wire (from the coil) about $\frac{1}{4}$" from the top of the rotor. With the ignition switch turned on, crank the engine with the starter. If the high tension spark jumps to the rotor, it is grounded (defective); that is, the rotor is allowing current to pass through it. If not, the cap must be defective. Inspect the cap for carbon tracks which indicate the passing of high voltage electricity.

3. Fuel System

You know that the purpose of the fuel system is to bring a combustible mixture of gasoline and air into the cylinders. The fuel system consists of the fuel tank, the fuel pump, the carburetor and intake manifold. Troubles in the fuel system can be caused by too little fuel, or none at all, in the combustion chambers — or too much.

In this system, the carburetor is the final step in preparing the fuel/air mixture. The method of checking used must be systematic and logical; random checks will not provide any sure results. We certainly have to check the carburetor, but this is the last step of the line. Therefore, we will start with determining if fuel is actually reaching the carburetor. Only then can we check it out.

a. Little or No Fuel to Carburetor (Test 1).

First make certain that there is fuel in the tank. Now, the air cleaner should have been removed in the earlier check and when you actuated the accelerator pump, what kind of stream of fuel did you see. (You can do this again at this point if necessary.) If the stream is missing completely, or very weak, you must test the fuel delivery system to make certain the carburetor has fuel. Only after you are certain fuel is being delivered to the carburetor can you begin testing the carburetor. So if there was a good stream of fuel being squirted into the carburetor throat, go to Test 3; otherwise, go to Test 2.

b. Fuel Delivery System (Test 2).

You should be here only if you were unable to be certain that enough fuel was being properly supplied to the carburetor. (A weak or no stream of fuel being pumped out by the accelerator pump.) Here we will test the fuel delivery system.

To test the fuel pump, disconnect the fuel line leading into the carburetor bowl and hold a container under the line to catch the gasoline as it spurts from the open end. (The ignition switch should be off; otherwise, the high tension wire should be removed from the center of the distributor cap to prevent the possibility of the engine starting and spraying gasoline all over the engine compartment.) If a good size stream of fuel flows from the pipe, and the trouble has been isolated to the fuel system by earlier tests, the defect must be in the carburetor. Go to Test 4. If no fuel flows, the trouble must be in the pump, lines or gas tank. Go to Test 2a.

(1) Pump and Supply Lines (Test 2a).

You are at this point because you have been able to determine that no fuel was being pumped to the carburetor from the output side of the fuel pump. We cannot say yet that the pump is at fault. Why? How do you know that there is fuel at the input side of the pump. Even though there is fuel in the tank, it might not be getting to the pump. Therefore, even if the pump is in good operating condition, if it's not getting fuel, there will be no discharge. To check the tank and lines, the fuel line should be disconnected at the inlet side of the fuel pump and at the fuel tank outlet and blown clear. If there are no obstructions or leaks, then either the fuel pump is defective and must be repaired or replaced, or the fuel tank vent is blocked. To check a blocked vent, replace the fuel lines, remove the tank filler cap and try the pump again. If fuel flows, then a vacuum was created in the tank. Replace the old cap with a new one. Otherwise, go to Test 2b.

(2) No Fuel or Obstructions (Test 2b).

If very little or no air passes through the line, it may be blocked or bent. To insure that there are no leaks, close off the pump end and try to blow out the line with compressed air. If air passes, there is a leak in the line which must be repaired.

c. Too Much Fuel (Test 3).

If you came as far as this point, you should be suspicious of too much fuel being present in the carburetor. Such conditions are usually caused by some malfunction within the carburetor itself. First you should check the carburetor for reasons causing flooding. Too much fuel can be caused by overchoking, or by a defective needle and seat in the carburetor float bowl which would allow fuel to bypass the needle and overflow into the intake manifold. This can be seen as a steady stream of raw gasoline coming out of the main jet when the engine is being cranked. Raw gasoline may also enter the intake manifold in excessive amounts when the engine is stopped after a very hard and prolonged pull. In this case, the heat developed by the engine may have caused the fuel to boil within the float chamber of the carburetor and percolate over the top of the main delivery tube into the intake manifold. Some carburetors are vented to prevent this possibility, but there are times when this vent is not functioning properly. Excessive amounts of raw gasoline may be seen by opening the throttle fully and looking down into the intake manifold through the carburetor bore. Also, if the choke sticks in the closed position, this can cause flooding and you can move it with your fingers, regulating it until the engine is running smoothly.

If all the above checks prove futile, you should assure yourself that flooding is occurring as follows: The best test, however, is the removal of a spark plug. An overchoked engine will have spark plugs wet with raw gasoline while a normal or starved engine will have dry spark plugs.

Under no circumstances should the throttle be pumped, as this will actuate the accelerator pump and force additional quantities of raw fuel into the intake manifold. This will only aggravate the situation; and since fuel is intentionally being pumped in by the accelerator pump, you won't be able to isolate the actual malady.

If, however, you made all the above-mentioned checks and are certain that flooding is occurring, go on to Test 3a.

(1) Fuel Pump Over-Delivery (Test 3a).

It is rarely the case but sometimes the wrong pump may be installed or the wrong pump pressure spring put in during the rebuilding. High pressure causes the float bowl level to rise, which richens the mixture proportionately. In some cases, however, high pressure forces the needle valve off of its seat and causes the carburetor to flood.

This, though, is an unusual case and this check should be done only as a last resort. To make this check, a capacity test should be performed. If this is not the trouble, then go back to Test 1 because something was missed along the way.

d. Too Little Fuel in Carburetor (Test 4).

Having checked out the fuel supply system to the carburetor and knowing that it is delivering fuel, you are able to evaluate the carburetor. Only after you are certain that fuel is arriving to the carburetor should you begin. The reason? How can you say that some carburetor circuit is not operating properly unless you know for certain that there is fuel available?

It is seldom that the carburetor itself causes starting trouble. Instances have been found of an inlet strainer plugged, or the float valve needle stuck in the closed position, but these are exceptions. Cases of an automatic choke not functioning are encountered more frequently in starting trouble. If the automatic choke does not close on a cold engine being cranked, hold your hand over the top of the carburetor bore to restrict the flow of air. Your hand would be acting as a choke valve.

You may have noticed that the tests of the fuel system were able to be made with certainty up to the carburetor. When the carburetor was encountered, we went through a series of tests which are designed to isolate the starting difficulty. However, if you were troubleshooting an automobile and performed all the above tests and,as a result, were certain the problem was within the carburetor, it's a pretty good indication that it needs at least a good cleaning, if not an overhaul.

The reason we discussed starting problems is that you can't very well diagnose an engine that isn't running. Presuming that you would replace or repair any defective part you would have found, and thus be able to get the engine running, we will move into the area of tune-up.

V. TUNE-UP PROCEDURES:

A. Introduction

Accurately diagnosing engine problems requires a combination of know-how, mechanical skill and good test equipment. However, testing equipment is only as good as the person operating it. So when we refer to tune-up, we simply mean diagnosing the engine problems and returning the existing factors to the original specifications.

You should attack the problem of engine diagnosis similarly to the method we used in troubleshooting the hard-starting car. Essentially, it is a logical process of isolating the particular malfunction.

Let us elaborate on "a logical process of isolating the particular malfunction". Before you repair or replace any part, you should know that something is the matter with it. This is the crux of any diagnosis — isolation of the malfunction. It's the same thing your doctor does when you're ill; he attempts to find out what is the specific thing that is causing you discomfort. He then prescribes remedies which he hopes will cure the affliction. Following this, he takes your money.

Again, before you begin repairs, you should specifically define the problem. Why? Well, if someone tows his car into your garage and you try to start it, and, in fact it doesn't start; and then you tell the guy his car won't start — he'll pop you one! He knows that. That's why he brought the car to you. He expects you to tell him what's wrong with his car, and give him an estimate of how much money and time it will take to repair it.

One thing you might do is simply start replacing different parts on the car with known good ones and eventually you might replace the right one. If you do this kind of trial and error work, you better not let him see you. You're obviously just guessing and going about finding the trouble pretty haphazardly. This does happen though. How often have you heard of soneone who has to take his car back to the same garage three and four times before he finally gets it properly serviced. This is the kind of mechanic you don't want to be; even though there are many of them. The reason they survive is simply because there aren't enough good ones around. Automobile owners are forced to take what they can get. Just about every good mechanic has a pretty regular following of customers who keep coming back and also spread his reputation.

Let's get back to the diagnosis. We made one point in the last paragraph. We said that you might start replacing different parts on the car with known good ones. "Known good ones" means when you diagnose you have to find some part or system that you say you know to be working properly. You do this, so that you have something to build upon. With experience you will develop an insight which will enable you to make reasonable speculations as to what could be the trouble with very little evidence; but even then, to isolate the problem, you must still follow a logical sequence. Let's go over what we did in troubleshooting the hard starting car.

First thing you did was to try and crank the engine with the starter. If it cranked, you presumed (and correctly so) that the cranking system was in order. Turning the engine over is the first step in its starting process. If you first started to check the ignition system, what would you have found out? Well, depending on what the trouble actually is, probably not too much.

Suppose you decided to check out the points. Suppose they checked o.k.? You can draw no conclusions except that the points are o.k. You're probably wondering why anyone would attack the problem this way in the first place. It is the time consuming trial and error approach. The logical approach is usually the common sense approach. It's not difficult; it simply makes sense. The approach that "makes sense" is the one to follow. It's that feeling of knowing that what you are doing is right. With sufficient knowledge and understanding, you will automatically take this systematic approach. Of course, though, you've got to know what are the functions of the various parts of an engine. When a person doesn't know or understand, then his approach is haphazard. He most likely feels a little bit exasperated or that his search is futile. When a person understands thoroughly the operations of the different parts of the engine, he can't help but follow a logical approach.

Back in our basic test to determine the cause of starting trouble, we tried to determine what was the cause of the engine being unable to be started. You first tested the cranking system, then the electrical, next the fuel system and finally you looked at the compression. What you did in each initial test was to check out the final stage of operation for the particular system. For example, you checked to see if a spark was produced at the end of the spark plug high tension leads. The reason for this was that if there was a spark you could be reasonably assured that the entire ignition system was in a working condition. If you got no spark, you knew that you were either making a poor test or that there was something the matter with the ignition system. Once you know how to make the test and have had some practice so that you are at ease and confident that you are doing it correctly, you can conclude that there is a malfunction in the ignition system.

It was at this point in the test that you began testing the individual components; that is, after you found that the entire system was not functioning properly, which you found out by checking the final results. In checking out the individual components, you began with testing the primary circuit. You almost had to do this; because how could you test the secondary circuit and draw any conclusion without knowing first that the primary was in working order? You would have done similarly if you were testing the starting circuit. For instance, you wouldn't try to test the starter motor until you were sure you had power from the battery. These steps make sense, don't they? All you're doing is — before you test something which depends on something else, you find out first if that "something else" is working. Then you go on and test the dependent part.

What you are also doing is isolating to fewer and fewer possibilities the probable cause of the trouble. For example, suppose you had checked out the primary circuit and were proceeding to test the secondary circuit. Only after you know that the coil is o.k., do you test the rotor. If you found that there was a spark jumping from the coil main high tension lead to the rotor, you concluded correctly that the rotor was defective. You isolated a defective part; that is, you found the rotor not to be functioning properly. Now there may be other problems in the ignition system, bad plugs, etc., or problems in the fuel system. But you simply continue to isolate the defective parts and repair or replace them. If you were only interested in getting the car started and the owner was satisfied, that would be the end of it. But if you were going to do a tune-up, you would be interested not only in getting the car started, but once it was started, performing a thorough diagnosis and returning all components to original or as close to original or as close to original specifications as possible.

What then are the most important and essential aspects of an engine diagnosis? (a) Isolation of a malfunction; (b) logical processes; (c) replace suspected parts with known good ones; (d) systematic testing; (e) all of these.

We discussed the method of simply going around replacing suspected parts with known good ones and concluded that it was a very poor method. Therefore, since (c) is not correct, neither is (e). Answer (d) is really a composition of (a) and (b).

As was stated at the beginning of this section, tune-up simply means diagnosing the engine problems and returning the existing factors to the original specifications. For this, you will be using special test equipment which greatly helps you in performing an accurate diagnosis.

B. Types of Test Equipment

The operation and use of the test equipment we will probably be using will be discussed here.

1. Compression Gauge

The compression gauge or compression tester is an instrument which measures the pressure built up in the cylinder by the piston as it reaches TDC on its compression stroke. The gauge is usually calibrated in pounds per square inch. Proper use of a compression gauge will detect worn piston rings, poorly seating valves and defective cylinder gaskets.

2. Tachometer

The tachometer is a device for measuring engine speeds in revolutions per minute. This electrical meter is connected to the ignition primary terminal of the distributor. It measures the number of times that the primary circuit is interrupted. This information is translated into engine RPM. A tachometer is very useful in balancing dual carburetors and for setting the idle speed to specifications.

3. Dwell Meter

The dwell meter is an instrument for measuring the degrees of rotation made by a distributor cam shaft from the instant the contact points close until they open again. This angle is known as cam angle, or contact or dwell angle. Increasing the cam angle decreases the contact point opening and vice versa.

4. Exhaust Analyzer

The exhaust analyzer or combustion analyzer is an instrument for accurate measurement of the air/fuel mixture by analysis of the exhaust gas. Its operation is based on the fact that different gasses possess different rates of heat conductivity. A rich fuel mixture conducts heat at a different rate than does a lean mixture. Therefore, it becomes a simple matter of measuring the resistance of a heating conductor exposed to air and comparing its resistance with a like heated conductor exposed to the exhaust gas. The resistance is measured by means of a device called a Wheatstone Bridge which responds to any small change in resistance caused by the thermal conductivity of the gas.

5. Vacuum Gauge

A vacuum gauge indicates the difference between atmospheric pressure and the air pressure at its sensor. For example, the gauge is often connected to the intake manifold to determine manifold vacuum (actually the difference between the outside atmospheric pressure and air pressure within the manifold). The gauge is calibrated in inches of mercury. This is only because this is the standard atmospheric pressure scale. Vacuum gauge readings are affected by atmospheric pressure (e.g. it will read approximately 1 inch lower for each 1000 feet of elevation), but it is not the specific reading that is important, rather what is important in using this gauge is the action of the needle. A vacuum gauge is an excellent indicator of the overall efficiency of engine operation.

6. Voltmeter

The voltmeter is an electrical device for making accurate voltage readings in the automotive electrical systems. Most voltmeters have a switch for selecting the desired voltage ranges, thus narrowing the scale and improving the reading accuracy. In addition, many instruments have the added capability for switching and may be used as an ammeter or ohmmeter. This increases the versatility of the instrument for use in engine diagnosis and tune-up.

7. Condenser Tester

A condenser tester is an electrical instrument for testing the condenser for leakage, capacitance and series resistance. These conditions all affect the performance of the ignition system. All condenser testers make these tests in similar fashion and have similar controls.

8. Timing Light

The timing light is simply a stroboscope which is connected to the ignition system where it receives its signal for each light flash. This on-off sequence makes a set of markings on the fly wheel or pulley stand still and match a pointer. This is known as the stroboscopic effect. Thus, if the marks do not line up with the pointer, adjustments can be made to set the ignition timing in accord with malfunction specifications.

9. Distributor Tester

The distributor tester is a special piece of test equipment for dynamically testing and aligning the distributor while removed from the engine. A distributor tester is very useful for aligning the points, setting the cam angle, determining cam load accuracy and making the mechanical and vacuum spark advance adjustments. Most distributor tester manufacturers have a series of detailed tests for operation of their particular piece of test equipment.

10. Oscilloscope

A recent introduction to the field of ignition testing is the oscilloscope. It has long been used by television repairmen to analyze the operation of complex circuitry. The scope televises the operation of the entire ignition system, putting the result in pattern form rather than in unit measure by use of separate meters as has been done in the past. The value of the scope as a testing instrument depends on the ability of the operator to interpret the meaning of the deviation from the normal wave patterns.

C. Engine Tune-up

The term engine tune-up implies that performance is peaked or improved. This is absolutely correct, so in this section, we are attempting to provide a list of those areas in an automobile which should either be inspected or tested during tune-up. If all of these checks are made, the serviceman should have a good idea of the condition of the automobile.

We are not going into detailed procedures or just what pieces of test equipment should be utilized for the various tests. Although the following information is quite general, it will apply in most cases. We simply want to talk about what a tune-up involves and what should be done, not how to do it. This type of information must be general, as there are so many differences in automobile manufacturers' models and years. Thus, for detailed test information and engine specifications, it is best to consult a manufacturer's shop manual. Also when special test equipment is utilized, detailed procedures and specifications associated with the equipment usually are provided by the manufacturer. For proper test equipment utilization, these instructions must be followed:

1. Battery and Battery Cable

Tests are made on a battery to determine its condition and state of charge. The ultimate result of these tests is to determine whether the battery is good, needs recharging or must be replaced. If a battery has failed, is low in charge or needs water frequently, good service demands that the reasons for any of these conditions be found.

There are two basic steps for checking the condition of the battery. In the past, the most widely used was to check the specific gravity of the battery electrolyte with a hydrometer. Now, the most widely used method is to use a special piece of test equipment for checking battery capacity under load. This is accomplished using a high rate discharge tester in conjunction with a voltmeter. Some battery test equipment manufacturers combine these two instruments into a single unit thus simplifying their use and interpretation. Be sure to follow the directions of the manufacturer when using this type of equipment.

In addition to testing, there are several other checks and services which should be performed during tune-up. These are: 1) An over-all visual inspection for battery cable and holder condition; 2) Addition of water to the proper level; 3) Cleaning and washing the battery cable and carrier; 4) Cleaning or replacing the cable clamp; 5) Tightening the cable clamp and lubricating with anti-corrosive paste; 6) Tightening and lubricating the carrier clamp.

2. Cranking Motor and Circuit

The entire cranking circuit requires very little in the way of tune-up or periodic maintenance; however, for tune-up, the system is very easily checked. Cranking the engine requires all of the system to be operating. If the engine is being turned over at the normal rate of speed, the entire cranking system is functioning.

Most cranking motors require no maintenance between engine overhauls and have sufficient lubrication and adequately large brushes to require no internal attention. However, at regular intervals, during an engine tune-up or when you are checking under the hood for any sort of trouble, it is a good idea to inspect the cranking motor and circuits. Check the cranking motor for tight mounting, electrical connections and the general condition of the unit as indicated by its operation.

3. Charging Circuits

Normal operation for the charging system is to have a fully charged battery and a low charging rate. This is accomplished by having a current-voltage regulator which automatically controls the charging rate of the generator or alternator that is going into the battery. In practice, the charging rate increases when the battery is discharged and decreases when it is charged. The charging rate should be cut down to a very low rate with a fully charged battery.

To test the charging system, crank the engine with the ignition switch off in order to discharge the battery slightly. On cars with an ignition key type starter switch, it may be necessary to remove the coil high tension wire from the distributor cap to prevent the engine from starting. Start the engine and note the charging rate. On a car without an ammeter, it is necessary to insert an ammeter in the charging circuit. As the engine is run for a short period, the charging rate should decrease with a properly operating regulator. If the ammeter does not show any charge after the above test, it is an indication that either the generator or regulator is at fault. If this situation occurs, then further troubleshooting tests must be initiated for isolation of the problem.

The conventional charging system tune-up is usually limited to the charging test, cleaning and lubricating and inspection for loose terminals, wire connections or obvious defects. One check which should be made for the D.C. generator can be made by removing the cover band. This will permit the inspection of the brushes, brush holders and commutator. If after removal of the cover band, particles of solder are found on the inside, it means that the generator has been overloaded and overheated so that the solder on the commutator bars has melted and been thrown out. In this situation, the generator will either have to be repaired or replaced.

Be sure that all leads, nuts, screws and terminals are tight. The generator mounting, drive blet tension and pulley nuts should also be checked.

Regulator tests are usually performed in conjunction with generator or alternator tests. However, if during the tune-up, a defective or malfunctioning regulator is discovered, refer to the applicable shop manual for detailed instructions for making the proper test and adjustment.

4. Distributor and Ignition Circuit

Efficient operation of the ignition system probably has a great deal more to do with the smooth operation of an internal combustion engine than any other mechanical or electrical part. The importance of the ignition system can be realized by the fact that every minute 20,000 sparks are developed and delivered to the spark plugs of an 8-cylinder engine running at high speed. These sparks must be distributed to each of the cylinders when they have been charged with an explosive air mixture that has been compressed to the point of maximum efficiency. Naturally, any slip-up in the chain of events needed to create and time the sparks will result in poor engine performance. Since the ignition system is so important in engine performance, and normal wear of parts causes tolerances to be exceeded, periodic maintenance tests should be performed.

During any tune-up operation, the engine ignition system should be visually checked prior to making replacements or adjustments. Ignition system checks should not start until after the battery and battery cable have been checked. Initial checking should start with the primary portion of the ignition circuit which includes the ignition switch, ignition switch wiring, coil and the distributor.

In the distributor, the most important components to check are the condenser and the ignition points. Much can be learned by checking the condition of the points. It is normal for the points to burn away over a long period of time; however, rapid burning or oxidizing of points indicates several other conditions which might exist, requiring further adjustment or replacement. Points that are burned or oxidized can be cleaned with thin fine cut contact file or stone. Emery cloth must never be used, since particles of emery may become embedded and cause rapid burning away of the points.

Ignition secondary circuit checks are made after assurance that the primary circuits are functioning properly. Start the checks by removing the coil high tension lead to the distributor and the spark plug leads from the distributor cap to the spark plugs. Inspect the terminals for looseness and corrosion. Inspect the wires for breaks and cracked insulation. Replace all defective wiring.

Clean the inside of the distributor cap and inspect it for cracks, burned contacts, permanent carbon tracks or a defective center carbon brush electrode. Remove dirt or corrosion from the sockets. Replace the cap if it is defective. Inspect the rotor for defects or cracks. Replace the rotor if it is defective.

Centrifugal and vacuum spark advance mechanism checks are limited to checking the freedom of action for advancing the breaker cam or distributor. Rotate the cam or entire distributor, depending upon the type of advance. Release and observe if the springs return the mechanism to the original position. A better test under dynamic conditions can be made by removing the distributor from the engine and checking on a distributor tester.

Coil and condenser tests should be performed by using special testing equipment.

Spark plugs should be examined carefully for cracked or broken insulators, badly pitted electrodes and other signs of failure. Examine the firing end of the spark plugs, noting the types of deposit and the degree of electrode erosion. Manufacturers' recommendations as to which plug to use are always based on average driving conditions. An engine driven under severe operating conditions requires a cooler running spark plug than do engines operating at continuously low operating speeds. Plugs that are too cold for the operating conditions of the engine soot up with oil and carbon and eventually short out. A plug that is too hot will blister and ignite the mixture prematurely by its white hot insulator. A properly operating plug will retain just enough heat to burn off the small amount of oil which is always present in the combustion gasses. In this case, the insulator should have a grayish tan color.

If after the examination, the circumstances warrant cleaning the plug, wipe the top of the porcelain clean with a good solvent. Blow dry with an air hose before continuing with the sand blaster plug cleaner. Sand blast the plugs. Be sure to tilt and turn the plugs constantly, so that the sand reaches all parts of the insulators. File and gap the electrode according to the manufacturer's recommendations.

Time should not be spent in cleaning spark plugs which have a cracked or blistered porcelain insulator or badly worn electrode, but should be replaced by a type that is recommended by the manufacturer.

5. Fuel and Carburetion

a. Fuel Pump and Filters

Any check of the automobile fuel and carburetion systems should start with a visual inspection of the entire system. Checks should be made on the fuel tank, lines, filters and screens for leaks or obstructions. The fuel pump should be tested for volume and pressure, which are the two most likely fuel pump troubles that affect engine performance. Low pressure will cause a lean mixture at high speeds and excessive pressure will cause high fuel consumption and carburetor flooding. Low volume will cause fuel starvation at high speeds.

If both the fuel pump volume and pressure are within specifications, and the pump and lines are in satisfactory condition, a vacuum test of the pump itself is not required as we know the pump is doing its job. If pump volume is low, but the pressure is within specification, the filter screen is probably dirty; clean it and then retest. On automobiles having replaceable filter elements, a test must be made with the filter removed. If the pump volume meets specification with the filter removed, replace the filter. If the pump volume for both tests is still below specification, repeat the test using an auxiliary fuel supply. If the pump does not meet specification, there is possibly a restriction in the fuel supply from the tank or the tank is not vented properly. These tests are to be performed with the fuel pump installed on the engine.

On automobiles with a replaceable filter element, make certain that the element has been changed in the prescribed maintenance mileage intervals. When in doubt, install a new filter element prior to performing any fuel pump test.

On systems having a sediment bowl, it is a good practice to remove the bowl and check the screen and rinse out the dirt prior to performing any fuel system testing. Dirt on the screen should be blown out with an air hose. The gasket should be checked prior to installation and replaced if necessary. After installation, again check for leaks. In practice, a clogged or restricted filter or screen is often the cause of fuel system malfunctions.

b. Carburetor

Carburetor problems are usually isolated to those caused by dirt accumulation in the fuel or air passages, improper idle adjustments or incorrect fuel level in the carburetor float bowl. Unfortunately, all three of these problems can affect engine performance in much the same way. Therefore, it is necessary to utilize all sources of information before and during tune-up for isolation and correction of the problems.

(1) Lean Mixture

The most commonly experienced fuel system trouble is the pause or flat spot on acceleration. If such a condition exists, check the operation of the accelerating pump system in the carburetor. To check this, remove the air cleaner and move the throttle back and forth. A stream of fuel should flow from the accelerating jet if it is functioning properly. If the fuel stream is missing completely, deflected to one side, or merely dribbling out, the carburetor must be overhauled.

Another lean condition may result from too little fuel being supplied by the carburetor during the main metering range of operation. Such a condition gives the feeling of lack of response by the engine when the throttle is opened gradually. This usually indicates that the demand for an enriched air/fuel mixture is not being provided. This could be caused by the carburetor linkage being out of adjustment; but more probable, would be the main metering or power system not functioning normally. In any case, check the linkage and adjust if necessary. Otherwise, the carburetor will have to be overhauled.

(2) Rich Mixture

Not only will a rich mixture cause a loss of power but excessive quantities of fuel will not vaporize and burn completely. The liquid fuel can wash the lubricant from the cylinder walls, destroying the upper cylinder lubrication. The result would be scuffed rings and excessive wear of the cylinder walls. This is turn would result in abnormal oil and fuel consumption.

A rich mixture is usually caused by the carburetor float system being worn or out of adjustment or by high fuel pump pressure. Either situation allows the needle valve to open, raising the float level and discharging gasoline into the high speed nozzle. A similar condition can result from an automobile choke being out of adjustment. In any of these situations, overhaul of the carburetor is recommended.

(3) Carburetor Checks

A number of quick checks can be made that will give a rough idea of whether the various carburetor circuits are functioning satisfactorily. The results of these checks should not be considered final. Accurate analysis of carburetor operation requires the use of an exhaust gas analyzer and an intake manifold vacuum gauge.

(a) Float level adjustment

High float level can sometimes be detected by engine flooding or signs of leakage on the side of the carburetor bowl. Another method is to start the engine and run at idle speed. Remove the air cleaner and note the condition of the high speed nozzle. If the nozzle tip is wet or discharging gasoline, the float level is probably high causing a continuous discharge of gasoline into the carburetor.

(b) Idle adjustments

Idle linkage adjustments usually show up by engine stalling, or rough idle. If set too fast, with an automatic transmission, it could cause a severe engagement during shifting after a cold start.

(c) Low speed and idle circuits

If the engine does not idle smoothly, most probably the idle circuit is malfunctioning. Slowly open the throttle to the equivalent of about 25 miles per hour engine speed. If the speed does not increase evenly, and the engine runs roughly through this speed range, the low speed circuit is out of order.

(d) Accelerator pump circuit

Open the throttle suddenly and note where the accelerator pump circuit discharges a flow of gasoline to the air horn. The flow should continue for a few moments after the throttle reaches the open position. On some carburetors, this can be better observed with the engine not running.

(e) High speed or power circuit

Set the engine speed equivalent to approximately 25 miles per hour, then slowly cover part of the air horn with the hand. The engine should speed up slightly, since this should cause a normal operating high speed circuit to discharge more gasoline. The high speed circuit is probably working improperly if the engine does not speed up somewhat.

There are manufacturers' recommended procedures for carburetor repair which should be followed. Also, each individual automobile manufacturer has specifications for make, model and year which should be the established standard. If satisfactory air fuel readings cannot be obtained, the carburetor should be overhauled. This requires removal of the carburetor from the car. If overhauled, carburetor adjustments should be made according to manufacturer information and specifications. All adjustments except the final engine idle, fuel mixture and throttle linkage adjustment can be performed prior to installing on the automobile.

6. Intake Manifold

A leaky intake manifold can cause hard starting, poor idling, burned spark plugs, burned valves, damaged pistons and rings, and in some engine designs, plug fouling and high oil consumption. Therefore, whenever feasible, the air intake manifold gasket should be checked for leaks and the manifold attaching bolts and nuts retourqued.

7. Air Cleaner Service

The air cleaner should be removed during tune-up for inspection. If necessary, the filter element should be cleaned or replaced. The usual recommendation is that this be done every time the engine oil is changed. However, if the car encounters unusual dusty conditions, the air cleaner element should be cleaned immediately afterwards. Remember, the primary purpose of the air cleaner is to keep damaging dust from entering the engine. If the element becomes clogged with dust, it cannot do its job and the engine will suffer.

D. Road Testing

Final testing after an engine tune-up should be the road test. This is the most important test as the automobile is operating under actual operating conditions. There really is no set pattern as to a list of detailed tests which must be performed during this phase. However, the best method is to try to operate the automobile under widely varying conditions; that is, under conditions of low speed, acceleration, heavy load, normal speeds and at the higher rates of speed. Heavy load condition usually requires going into an area where there is a sharp enough upgrade to enable operation of the acceleration and power circuits in the carburetor. An engine operating under an extremely heavy load condition provides a means for detection of ignition problems — usually timing and in the distributor spark advance mechanisms.

High speed conditions can be simulated by keeping the transmission in the lower ranges during driving. The engine will be running at a higher RPM while traveling at a lower miles per hour. This is a means for detecting fuel pump troubles, ignition point bounce, or the coil cutting out. The road test calls for strict observation on the part of the serviceman, so any abnormalities should be noted and corrected. Usually this requires returning the automobile to the shop for replacement of a defective part or for rechecking adjustments with test equipment.